DOCUMENT RESUME

ED 209 114 SE 035 923

TITLE	Applied Ecology Seminar. Training Manual.
INSTITUTION	Office of Water Program Operations (EPA), Cincinnati, Ohio. National Training and Operational Technology Center.
REPORT NO	EPA-430/1-79-014
PUB DATE	Dec 79
NOTE	203p.: Contains occasional light and broken type.
AVAILABLE FROM	EPA Instructional Resources Center, 1200 Chambers Rd., 3rd Floor, Columbus, OH 43212 ($1.00 plus $0.03 per page).
EDRS PRICE	MF01/PC09 Plus Postage.
DESCRIPTORS	*Administration; *Biological Sciences; *Data Analysis; Data Collection; Ecological Factors; *Ecology; *Environmental Standards; Marine Biology; Postsecondary Education; *Science Education; Water Pollution
IDENTIFIERS	*Water Quality

ABSTRACT

Presented is material on planning, administering, collecting, evaluating, interpreting, and reporting biological data related to water quality studies in both fresh and marine waters. Topics include aquatic ecology, water pollution, taxonomy, bacteriology, bioassays, water quality enhancement, and administration of water quality standards. Each of the 19 chapters includes reading material and selected references. (CO)

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United States
Environmental Protection
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National Training
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Cincinnati OH 45268

EPA-430/1-79-014
December 1979

Water

EPA

Applied Ecology Seminar

Training Manual

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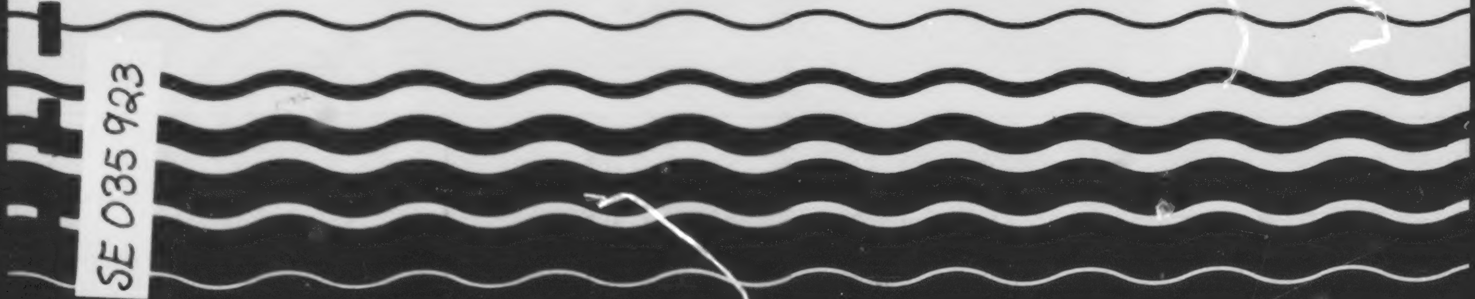

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EPA-430/1-79-014
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Applied Ecology Seminar

This seminar is for those concerned with planning, administering, collecting, evaluating, interpreting and reporting biological data related to water quality studies in both fresh and marine waters.

After successfully completing the course, the student will be able to better utilize biological techniques which are fundamental in water pollution control. He/she will better understand the advantages and potential contributions of biological data and investigations to administrators, project leaders and others. Biologists will better understand the limitations and restrictions placed on the administrator, and the nature of biological data which will be most useful for the improvement of water quality.

The training consists of formal presentations followed by informal discussions, a field trip and laboratory studies.

U. S. ENVIRONMENTAL PROTECTION AGENCY
Office of Water Program Operations
National Training and Operational Technology Center

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CONTENTS

Title or Description	Outline Number
Global Deterioration and Our Environmental Crisis	1
The Aquatic Environment	2
The Laws of Ecology	3
Aquatic Organisms of Significance in Pollution Surveys	4
Biological Aspects of Natural Self Purification	5
Significance of Eutrophication	6
Pollution of the Marine Environment	7
Water Temperature and Water Quality	8
Biotic Effects of Solids	9
Effects of Pollution on Fish	10
Critical Problems in Systematics	11
The System of Biological Classification	12
The Cycling of Radionuclides in the Aquatic Environment	13
Procedures for Fish Kill Investigations	14
Special Applications and Procedures for Bioassay	15
Using Benthic Biota in Water Quality Evaluations	16
The Interpretation of Biological Data with Reference to Water Quality	17
The Physical and Biological Components of the Estuarine Ecosystem and Their Analysis	18
Case Preparation and Courtroom Procedure	19

GLOBAL ENVIRONMENTAL QUALITY

I FROM LOCAL TO REGIONAL TO GLOBAL PROBLEMS

A Environmental problems do not stop at national frontiers, or ideological barriers. Pollution in the atmosphere and oceans taints all nations, even those benignly favored by geography, climate, or natural resources.

1 The smokestacks of one country often pollute the air and water of another.

2 Toxic effluents poured into an international river can kill fish in a neighboring nation and ultimately pollute international seas.

B In Antarctica, thousands of miles from pollution sources, penguins and fish contain DDT in their fat. Recent layers of snow and ice on the white continent contain measurable amounts of lead. The increase can be correlated with the earliest days of lead smelting and combustion of leaded gasolines. PCB's are universally distributed.

C International cooperation, therefore, is necessary on many environmental fronts.

1 Sudden accidents that chaotically damage the environment - such as oil spills from a tanker at sea - require international cooperation both for prevention and for cleanup.

2 Environmental effects cannot be effectively treated by unilateral action.

3 The ocean can no longer be considered a dump.

D "One of the penalties of an ecological education is that one lives alone in a world of wounds. Much of the damage inflicted on land is quite invisible to laymen. An ecologist must either harden his shell and make believe that the consequences of science are none of his business, or he must be the doctor who sees the marks of death in a community that believes itself well and does not want to be told otherwise." Aldo Leopold

II CHANGES IN ECOSYSTEMS ARE OCCURRING CONTINUOUSLY

A Myriad interactions take place at every moment of the day as plants and animals respond to variations in their surroundings and to each other. Evolution has produced for each species, including man, a genetic composition that limits how far that species can go in adjusting to sudden changes in its surroundings. But within these limits the several thousand species in an ecosystem, or for that matter, the millions in the biosphere, continuously adjust to outside stimuli. Since interactions are so numerous, they form long chains of reactions.

B Small changes in one part of an ecosystem are likely to be felt and compensated for eventually throughout the system. Dramatic examples of change can be seen where man has altered the course of nature. It is vividly evident in his well-intentioned but poorly thought out tampering with river, lake, and other ecosystems.

1 The Aswan High Dam

2 The St. Lawrence Seaway

3 Lake Kariba

4 The Great Lakes

5 Valley of Mexico

6 California earthquake (Scientific American 3981, p. 333)

7 Everglades and the Miami, Florida Jetport

8 Copperhill, Tennessee (Copper Basin)

9 (You may add others)

C Ecosystem Stability

1 The stability of a particular ecosystem depends on its diversity. The more interdependencies in an ecosystem, the greater the chances that it will be able to compensate for changes imposed upon it.

2 A cornfield or lawn has little natural stability. If they are not constantly and carefully cultivated, they will not remain cornfields or lawns but will soon be overgrown with a wide variety of hardier plants constituting a more stable ecosystem.

3 The chemical elements that make up living systems also depend on complex, diverse sources to prevent cyclic shortages or oversupply.

4 Similar diversity is essential for the continued functioning of the cycle by which atmospheric nitrogen is made available to allow life to exist. This cycle depends on a wide variety of organisms, including soil bacteria and fungi, which are often destroyed by pesticides in the soil.

5 A numerical expression of diversity is often used in defining stream water quality.

D Biological Pollution

Contamination of living native biotas by introduction of exotic life forms has been called biological pollution by Lachner et al. Some of these introductions are compared to contamination as severe as a dangerous chemical release. They also threaten to replace known wildlife resources with species of little or unknown value.

1 Tropical areas have especially been vulnerable. Florida is referred to as "a biological cesspool of introduced life."

2 Invertebrates

a Asian Clams have a pelagic veliger larvae, thus, a variety of hydro installations are vulnerable to subsequent pipe clogging by the adult clams.

b Melanian snails are intermediate hosts for various trematodes parasitic on man.

3 Vertebrates

a At least 25 exotic species of fish have been established in North America.

b Birds, including starlings and cattle egrets.

c Mammals, including nutria.

4 Aquatic plants

Over twenty common exotic species are growing wild in the United States. The problem of waterway clogging has been especially severe in parts of the Southeast.

5 Pathogens and Pests

Introduction of insect pests and tree pathogens have had severe economic effects.

III LAWS OF ECOLOGY

A Four principles have been enunciated by Dr. Barry Commoner.

1 Everything is connected to everything else.

2 Everything must go somewhere.

3 Nature knows best.

4 There is no such thing as a free lunch.

B These may be summarized by the principle, "you can't do just one thing."

IV THE THREE PRINCIPLES OF ENVIRONMENTAL CONTROL (Wolman)

A You can't escape.

B You have to organize.

C You have to pay.

V LEOPOLD'S PRINCIPLE OF BIOTIC CAPITAL

"The releases of biotic capital tend to becloud or postpone the penalties of violence". Can you apply this to other parts of this outline?

VI POLLUTION COMES IN MANY PACKAGES

A The sources of air, water, and land pollution are interrelated and often interchangeable.

1 A single source may pollute the air with smoke and chemicals, the land with solid wastes, and a river or lake with chemical and other wastes.

2 Control of air pollution may produce more solid wastes, which then pollute the land or water.

3 Control of wastewater effluent may convert it into solid wastes, which must be disposed of on land, or by combustion to the air.

4 Some pollutants - chemicals, radiation, pesticides - appear in all media.

B "Disposal" is as important and as costly as purification.

VII PERSISTENT CHEMICALS IN THE ENVIRONMENT

Increasingly complex manufacturing processes, coupled with rising industrialization, create greater amounts of exotic wastes potentially toxic to humans and aquatic life.

They may also be teratogenic (toxicants responsible for changes in the embryo with resulting birth defects, ex., thalidomide), mutagenic (insults which produce mutations, ex., radiation), or carcinogenic (insults which induce cancer, ex., benzopyrenes) in effect. Most carcinogens are also mutagenic. For all of these there are no threshhold levels as in toxicity. Fortunately there are simple rapid tests for mutagenicity using bacteria. Tests with animals are not always conclusive.

A Metals - current levels of cadmium, lead, and other substances are a growing concern for they affect not only fish and wildlife but ultimately man himself. Mercury pollution, for example, has become a serious problem, yet mercury has been present on earth since time immemorial.

B Pesticides

1 A pesticide and its metabolites may move through an ecosystem in many ways. Hard (pesticides which are persistent, having a long half-life in the environment includes the organochlorines, ex., DDT) pesticides ingested or otherwise borne by the target species will stay in the environment, possibly to be recycled or concentrated further through the natural action of food chains if the species is eaten. Most of the volume of pesticides do not reach their target at all.

2 Biological magnification

Initially, low levels of persistent pesticides in air, soil, and water may be concentrated at every step up the food chain. Minute aquatic organisms and scavengers, which screen water and bottom mud having pesticide levels of a few parts per billion, can accumulate levels measured in parts per million - a thousandfold increase. The sediments including fecal deposits are continuously recycled by the bottom animals.

a Oysters, for instance, will concentrate DDT 70, 000 times higher in their tissues than it's concentration in surrounding water. They can also partially cleanse themselves in water free of DDT.

b Fish feeding on lower organisms build up concentrations in their visceral fat which may reach several thousand parts per million and levels in their edible flesh of hundreds of parts per million.

c Larger animals, such as fish-eating gulls and other birds, can further concentrate the chemicals. A survey on organochlorine residues in aquatic birds in the Cnadian prairie provinces showed that California and ring-billed gulls were among the most contaminated. Since gulls breed in colonies, breeding population changes can be detected and related to levels of chemical contamination. Ecological research on colonial birds to monitor the effects of chemical pollution on the environment is useful.

C "Polychlorinated biphenyls" (PCB's). PCB's are used in plasticizers, asphalt, ink, paper, and a host of other products. Action has been taken to curtail their release to the environment, since their effects are similar to hard pesticides.

D Other compounds which are toxic and accumulate in the ecosystem:

1 Phalate esters - may interfere with pesticide analyses

2 Benzopyrenes

E Refractory compounds like pentachlorophenal and hexachlorophene are poorly removed by both water treatment plants and wastewater treatment plants.

F It is estimated that 80% to 90% of cancers are caused by chemicals both in the working environment and total environment. This is shown by high risk industries and living areas.

G Most of the problems of persistent and dangerous chemicals in the environment are "after-the-fact". The solution obviously is tied to prevention. This is extremely complicated by economics, ignorance, and decision as to risks involved. Some advertising slogans now have more than an intended meaning.

H Wittingly or unwittingly we have all become a King Mithridates. And even a fish is no longer a fish!

VIII EXAMPLES OF SOME EARLY WARNING SIGNALS THAT HAVE BEEN DETECTED BUT FORGOTTEN, OR IGNORED.

A Magnetic micro-spherules in lake sediments now used to detect changes in industrialization indicate our slowness to recognize indicators of environmental change.

B Salmonid fish kills in poorly buffered clean lakes in Sweden. Over the past years there had been a successive increase of SO_2 in the air and precipitation. Thus, air-borne contamination from industrialized European countries had a great influence on previously unpolluted waters and their life.

C Minimata, Japan and mercury pollution.

D Organochlorine levels in commercial and sport fishing stocks, ex., the lower Mississippi River fish kills.

E You may complete the following:

1

2

IX SUMMARY

A Ecosystems of the world are linked together through biogeochemical cycles which are determined by patterns of transfer and concentrations of substances in the biosphere and surface rocks.

B Organisms determine or strongly influence chemical and physical characteristics of the atmosphere, soil, and waters.

C The inability of man to adequately predict or control his effects on the environment is indicated by his lack of knowledge concerning the net effect of atmospheric pollution on the earth's climate.

D Serious potential hazards for man which are all globally dispersed, are radionuclides, organic chemicals, pesticides, and combustion products.

E Environmental destruction is in lockstep with our population growth.

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Descriptors: Environmental Effects, Ecosystems

THE AQUATIC ENVIRONMENT

Part 1: The Nature and Behavior of Water

I INTRODUCTION

The earth is physically divisible into the lithosphere or land masses, and the hydrosphere which includes the oceans, lakes, streams, and subterranean waters; and the atmosphere.

A Upon the hydrospere are based a number of sciences which represent different approaches. Hydrology is the general science of water itself with its various special fields such as hydrography, hydraulics, etc. These in turn merge into physical chemistry and chemistry.

B Limnology and oceanography combine aspects of all of these, and deal not only with the physical liquid water and its various naturally occurring solutions and forms, but also with living organisms and the infinite interactions that occur between them and their environment.

C Water quality management, including pollution control, thus looks to all branches of aquatic science in efforts to coordinate and improve man's relationship with his aquatic environment.

II SOME FACTS ABOUT WATER

A Water is the only abundant liquid on our planet. It has many properties most unusual for liquids, upon which depend most of the familiar aspects of the world about us as we know it. (See Table 1)

TABLE 1

UNIQUE PROPERTIES OF WATER

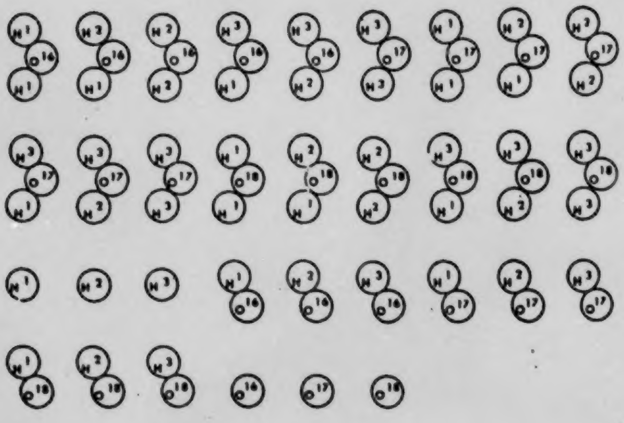
Property	Significance
Highest heat capacity (specific heat) of any solid or liquid (except NH_3)	Stabilizes temperatures of organisms and geographical regions
Highest latent heat of fusion (except NH_3)	Thermostatic effect at freezing point
Highest heat of evaporation of any substance	Important in heat and water transfer of atmosphere
The only substance that has its maximum density as a liquid (4°C)	Fresh and brackish waters have maximum density above freezing point. This is important in vertical circulation pattern in lakes.
Highest surface tension of any liquid	Controls surface and drop phenomena, important in cellular physiology
Dissolves more substances in greater quantity than any other liquid	Makes complex biological system possible. Important for transportation of materials in solution.
Pure water has the highest di-electric constant of any liquid	Leads to high dissociation of inorganic substances in solution
Very little electrolytic dissociation	Neutral, yet contains both H^+ and OH^- ions
Relatively transparent	Absorbs much energy in infra red and ultra violet ranges, but little in visible range. Hence "colorless"

B Physical Factors of Significance

1 Water substance

Water is not simply "H_2O" but in reality is a mixture of some 33 different substances involving three isotopes each of hydrogen and oxygen (ordinary hydrogen H^1, deuterium H^2, and tritium H^3; ordinary oxygen O^{16}, oxygen 17, and oxygen 18) plus 15 known types of ions. The molecules of a water mass tend to associate themselves as polymers rather than to remain as discrete units. (See Figure 1)

SUBSTANCE OF PURE WATER


H^1 O^{16} H^1
H^2 O^{16} H^1
H^2 O^{16} H^2
H^3 O^{16} H^1
H^3 O^{16} H^2
H^3 O^{17} H^3
H^1 O^{17} H^1
H^2 O^{17} H^1
H^2 O^{17} H^2
H^3 O^{17} H^1
H^3 O^{17} H^2
H^3 O^{17} H^3
H^1 O^{18} H^1
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H^3 O^{18} H^3
H^1
H^2
H^3
H^1 O^{16}
H^2 O^{16}
H^3 O^{16}
H^1 O^{17}
H^2 O^{17}
H^3 O^{17}
H^1 O^{18}
H^2 O^{18}
H^3 O^{18}
O^{16}
O^{17}
O^{18}

Figure 1

2 Density

a Temperature and density: Ice. Water is the only known substance in which the solid state will float on the liquid state. (See Table 2) This ensures that ice usually forms on top of a body of water and tends to insulate the remaining water mass from further loss of heat. Did ice sink, there could be little or no carryover of aquatic life from season to season in the higher latitudes. Frazil or needle ice forms colloidally at a few thousandths of a degree below 0° C. It is adhesive and may build up on submerged objects as "anchor ice", but it is still typical ice (ice I).

TABLE 2

EFFECTS OF TEMPERATURE ON DENSITY OF PURE WATER AND ICE*

Temperature (°C)	Density	
	Water	Ice**
-10	.99815	.9397
- 8	.99869	.9360
- 6	.99912	.9020
- 4	.99945	.9277
- 2	.99970	.9229
0	.99987----	.9168
2	.99997	
4	1.00000	
6	.99997	
8	.99988	
10	.99973	
20	.99823	
40	.99225	
60	.98324	
80	.97183	
100	.95838	

* Tabular values for density, etc., represent estimates by various workers rather than absolute values, due to the variability of water.

** Regular ice is known as "ice I". Four or more other "forms" of ice are known to exist (ice II, ice III, etc.), having densities at 1 atm. pressure ranging from 1.1595 to 1.67. These are of extremely restricted occurrence and may be ignored in most routine operations.

1) Seasonal increase in solar radiation annually warms surface waters in summer while other factors result in winter cooling. The density differences resulting establish two classic layers: the epilimnion or surface layer, and the hypolimnion or lower layer, and in between is the thermocline or shear-plane.

2) While for certain theoretical purposes a "thermocline" is defined as a zone in which the temperature changes one degree centigrade for each meter of depth, in practice, any transitional layer between two relatively stable masses of water of different temperatures may be regarded as a thermocline.

3) Obviously the greater the temperature differences between epilimnion and hypolimnion and the sharper the gradient in the thermocline, the more stable will the situation be.

4) From information given above, it should be evident that while the temperature of the hypolimnion rarely drops much below 4° C, the epilimnion may range from 0° C upward.

5) When epilimnion and hypolimnion achieve the same temperature, stratification no longer exists. The entire body of water behaves hydrologically as a unit, and tends to assume uniform chemical and physical characteristics. Even a light breeze may then cause the entire body of water to circulate. Such events are called overturns, and usually result in water quality changes of considerable physical, chemical, and biological significance. Mineral-rich water from the hypolimnion, for example, is mixed with oxygenated water from the epilimnion. This usually triggers a sudden growth or "bloom" of plankton organisms.

6) When stratification is present, however, each layer behaves relatively independently, and significant quality differences may develop.

7) Thermal stratification as described above has no reference to the size of the water mass; it is found in oceans and puddles.

b The relative densities of the various isotopes of water influence its molecular composition. For example, the lighter O_{16} tends to go off first in the process of evaporation, leading to the relative enrichment of air by O_{16} and the enrichment of water by O_{17} and O_{18}. This can lead to a measurably higher O_{18} content in warmer climates. Also, the temperature of water in past geologic ages can be closely estimated from the ratio of O_{18} in the carbonate of mollusc shells.

c Dissolved and/or suspended solids may also affect the density of natural water masses (see Table 3)

TABLE 3
EFFECTS OF DISSOLVED SOLIDS ON DENSITY

Dissolved Solids (Grams per liter)	Density (at 4° C)
0	1.00000
1	1.00085
2	1.00169
3	1.00251
10	1.00818
35 (mean for sea water)	1.02822

d Types of density stratification

1) Density differences produce stratification which may be permanent, transient, or seasonal.

2) Permanent stratification exists for example where there is a heavy mass of brine in the deeper areas of a basin which does not respond to seasonal or other changing conditions.

3) Transient stratification may occur with the recurrent influx of tidal water in an estuary for example, or the occasional influx of cold muddy water into a deep lake or reservoir.

4) Seasonal stratification is typically thermal in nature, and involves the annual establishment of the epilimnion, hypolimnion, and thermocline as described above.

5) Density stratification is not limited to two-layered systems; three, four, or even more layers may be encountered in larger bodies of water.

e A "plunge line" (sometimes called "thermal line") may develop at the mouth of a stream. Heavier water flowing into a lake or reservoir plunges below the lighter water mass of the epiliminium to flow along at a lower level. Such a line is usually marked by an accumulation of floating debris.

f Stratification may be modified or entirely suppressed in some cases when deemed expedient, by means of a simple air lift.

3 The viscosity of water is greater at lower temperatures (see Table 4). This is important not only in situations involving the control of flowing water as in a sand filter, but also since overcoming resistance to flow generates heat, it is significant in the heating of water by internal friction from wave and current action. Living organisms more easily support themselves in the more viscous (and also denser) cold waters of the arctic than in the less viscous warm waters of the tropics. (See Table 4).

TABLE 4

VISCOSITY OF WATER (In millipoises at 1 atm)

	Dissolved solids in g/L			
Temp. ° C	0	5	10	30
-10	26.0	----	----	----
- 5	21.4	----	----	----
0	17.94	18.1	18.24	18.7
5	15.19	15.3	15.5	16.0
10	13.10	13.2	13.4	13.8
30	8.00	8.1	8.2	8.6
100	2.84	----	----	----

4 Surface tension has biological as well as physical significance. Organisms whose body surfaces cannot be wet by water can either ride on the surface film or in some instances may be "trapped" on the surface film and be unable to re-enter the water.

5 Heat or energy

Incident solar radiation is the prime source of energy for virtually all organic and most inorganic processes on earth. For the earth as a whole, the total amount (of energy) received annually must exactly balance that lost by reflection and radiation into space if climatic and related conditions are to remain relatively constant over geologic time.

a For a given body of water, immediate sources of energy include in addition to solar irradiation: terrestrial heat, transformation of kinetic energy (wave and current action) to heat, chemical and biochemical reactions, convection from the atmosphere, and condensation of water vapor.

b The proportion of light reflected depends on the angle of incidence, the temperature, color, and other qualities of the water; and the presence or absence of films of lighter liquids such as oil. In general, as the depth increases arithmetically, the light tends to decrease geometrically. Blues, greens, and yellows tend to penetrate most deeply while ultra violet, violets, and orange-reds are most quickly absorbed. On the order of 90% of the total illumination which penetrates the surface film is absorbed in the first 10 meters of even the clearest water, thus tending to warm the upper layers.

6 Water movements

a Waves or rhythmic movement

1) The best known are traveling waves caused by wind. These are effective only against objects near the surface. They have little effect on the movement of large masses of water.

2) Seiches

Standing waves or seiches occur in lakes, estuaries, and other enclosed bodies of water, but are seldom large enough to be observed. An "internal wave or seich" is an oscillation in a submersed mass of water such as a hypolimnion, accompanied by compensating oscillation in the overlying water so that no significant change in surface level is detected. Shifts in submerged water masses of this type can have severe effects on the biota and also on human water uses where withdrawals are confined to a given depth. Descriptions and analyses of many other types and sub-types of waves and wave-like movements may be found in the literature.

b Tides

1) Tides are the longest waves known, and are responsible for the once or twice a day rythmic rise and fall of the ocean level on most shores around the world.

2) While part and parcel of the same phenomenon, it is often convenient to refer to the rise and fall of the water level as "tide," and to the resulting currents as "tidal currents."

3) Tides are basically caused by the attraction of the sun and moon on water masses, large and small; however, it is only in the oceans and possibly certain of the larger lakes that true tidal action has been demonstrated. The patterns of tidal action are enormously complicated by local topography, interaction with seiches, and other factors. The literature on tides is very large.

c Currents (except tidal currents) are steady arythmic water movements which have had major study only in oceanography although they are most often observed in rivers and streams. They are primarily concerned with the translocation of water masses. They may be generated internally by virtue of density changes, or externally by wind or terrestrial topography. Turbulence phenomena or eddy currents are largely responsible for lateral mixing in a current. These are of far more importance in the economy of a body of water than mere laminar flow.

d Coriolis force is a result of interaction between the rotation of the earth, and the movement of masses or bodies on the earth. The net result is a slight tendency for moving objects to veer to the right in the northern hemisphere, and to the left in the southern hemisphere. While the result in fresh waters is usually negligible, it may be considerable in marine waters. For example, other factors permitting, there is a tendency in estuaries for fresh waters to move toward the ocean faster along the right bank, while salt tidal waters tend to intrude farther inland along the left bank. Effects are even more dramatic in the open oceans.

e Langmuir circulation (or L. spirals) is the interlocking rotation of somewhat cylindrical masses of surface water under the influence of wind action. The axes of the cylinders are parallel to the direction of the wind. To somewhat oversimplify the concept, a series of adjoining cells might be thought of as chains of interlocking gears in which at every other contact the teeth are rising while at the alternate contacts, they are sinking (Figure 2).

The result is elongated masses of water rising or sinking together. This produces the familiar "wind rows" of foam, flotsam and jetsam, or plankton often seen streaking windblown lakes or oceans. Certain zoo-plankton struggling to maintain a position near the surface tend to collect in the down current between two Langmuir cells, causing such an area to be called the "red dance", while the clear upwelling water between is the "blue dance".

This phenomenon may be important in water or plankton sampling on a windy day.

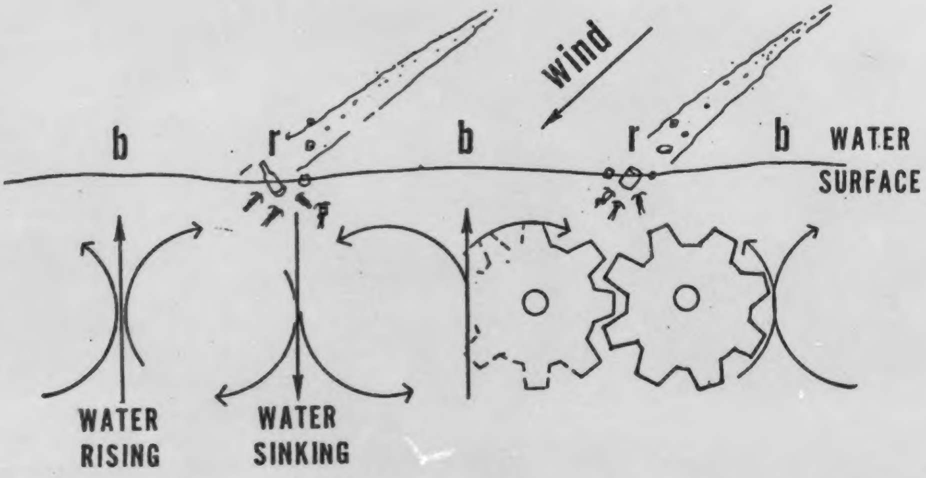

Figure 2. Langmuire Spirals
b. Blue dance, water rising. r. Red dance, water sinking, floating or swimming objects concentrated.

6 The pH of pure water has been determined between 5.7 and 7.01 by various workers. The latter value is most widely accepted at the present time. Natural waters of course vary widely according to circumstances.

C The elements of hydrology mentioned above represent a selection of some of the more conspicuous physical factors involved in working with water quality. Other items not specifically mentioned include: molecular structure of waters, interaction of water and radiation, internal pressure, acoustical characteristics, pressure-volume-temperature relationships, refractivity, luminescence, color, dielectrical characteristics and phenomena, solubility, action and interactions of gases, liquids and solids, water vapor, phenomena of hydrostatics and hydrodynamics in general.

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Part 2: The Aquatic Environment as an Ecosystem

I INTRODUCTION

Part 1 introduced the lithosphere and the hydrosphere. Part 2 will deal with certain general aspects of the biosphere, or the sphere of life on this earth, which photographs from space have shown is a finite globe in infinite space.

This is the habitat of man and the other organisms. His relationships with the aquatic biosphere are our common concern.

II THE BIOLOGICAL NATURE OF THE WORLD WE LIVE IN

A We can only imagine what this world must have been like before there was life.

B The world as we know it is largely shaped by the forces of life.

1 Primitive forms of life created organic matter and established soil.

2 Plants cover the lands and enormously influence the forces of erosion.

3 The nature and rate of erosion affect the redistribution of materials (and mass) on the surface of the earth (topographic changes).

4 Organisms tie up vast quantities of certain chemicals, such as carbon and oxygen.

5 Respiration of plants and animals releases carbon dioxide to the atmosphere in influential quantities.

6 CO_2 affects the heat transmission of the atmosphere.

C Organisms respond to and in turn affect their environment. Man is one of the most influential.

III ECOLOGY IS THE STUDY OF THE INTERRELATIONSHIPS BETWEEN ORGANISMS, AND BETWEEN ORGANISMS AND THEIR ENVIRONMENT.

A The ecosystem is the basic functional unit of ecology. Any area of nature that includes living organisms and nonliving substances interacting to produce an exchange of materials between the living and nonliving parts constitutes an ecosystem. (Odum, 1959)

1 From a structural standpoint, it is convenient to recognize four constituents as composing an ecosystem (Figure 1).

a Abiotic NUTRIENT MINERALS which are the physical stuff of which living protoplasm will be synthesized.

b Autotrophic (self-nourishing) or PRODUCER organisms. These are largely the green plants (holophytes), but other minor groups must also be included (See Figure 2). They assimilate the nutrient minerals, by the use of considerable energy, and combine them into living organic substance.

c Heterotrophic (other-nourishing) CONSUMERS (holozoic), are chiefly the animals. They ingest (or eat) and digest organic matter, releasing considerable energy in the process.

d Heterotrophic REDUCERS are chiefly bacteria and fungi that return complex organic compounds back to the original abiotic mineral condition, thereby releasing the remaining chemical energy.

2 From a functional standpoint, an ecosystem has two parts (Figure 2)

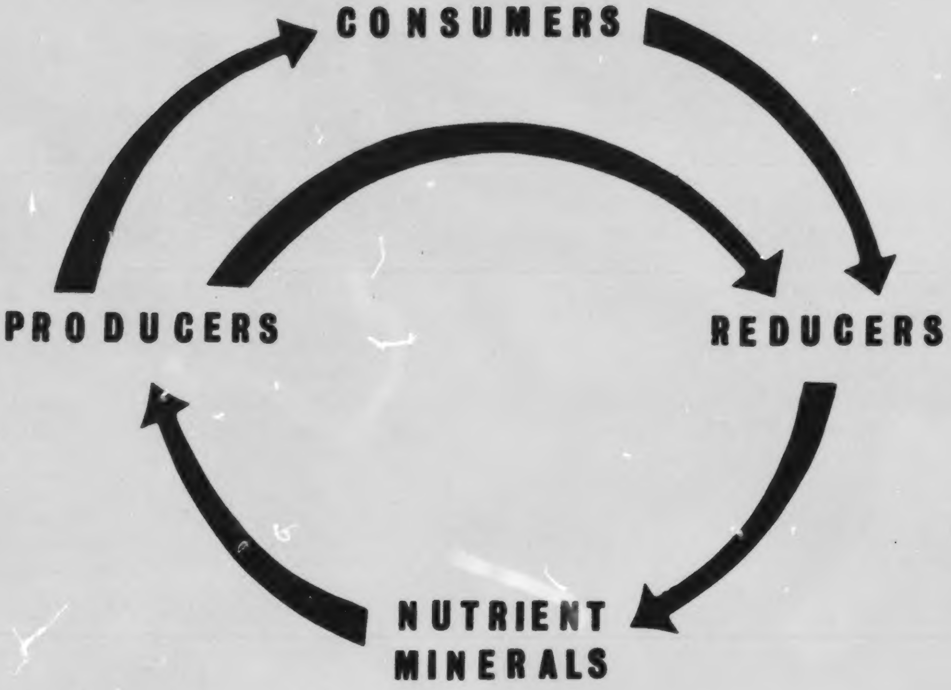

FIGURE 1

a The autotrophic or producter organisms, which utilize light energy or the oxidation of inorganic compounds as their sole energy source.

b The heterotropic or consumer and reducer organisms which utilizes organic compounds for its energy and carbon requirements.

3 Unless the autotrophic and heterotrophic phases of the cycle approximate a dynamic equilibrium, the ecosystem and the environment will change.

B Each of these groups includes simple, single-celled representatives, persisting at lower levels on the evolutionary stems of the higher organisms. (Figure 2)

1 These groups span the gaps between the higher kingdoms with a multitude of transitional forms. They are collectively called the PROTISTA and MONERA.

2 These two groups can be defined on the basis of relative complexity of structure.

a The bacteria and blue-green algae, lacking a nuclear membrane are the Monera.

b The single-celled algae and protozoa are Protista.

C Distributed throughout these groups will be found most of the traditional "phyla" of classic biology.

IV FUNCTIONING OF THE ECOSYSTEM

A A food chain is the transfer of food energy from plants through a series of organisms with repeated eating and being eaten. Food chains are not isolated sequences but are interconnected.

RELATIONSHIPS BETWEEN FREE LIVING AQUATIC ORGANISMS

Energy Flows from Left to Right, General Evolutionary Sequence is Upward

PRODUCERS	**CONSUMERS**		**REDUCERS**
Organic Material Produced, Usually by Photosynthesis	Organic Material Ingested or Consumed Digested Internally		Organic Material Reduced by Extracellular Digestion and Intracellular Metabolism to Mineral Condition
ENERGY STORED	ENERGY RELEASED		ENERGY RELEASED
Flowering Plants and Gymnosperms	Arachnids	Mammals	Basidiomycetes
	Insects	Birds	
Club Mosses, Ferns	Crustaceans	Reptiles	
	Segmented Worms	Amphibians	
Liverworts, Mosses	Molluscs	Fishes	Fungi Imperfecti
Multicellular Green Algae	Bryozoa	Primitive Chordates	
	Rotifers		Ascomycetes
	Roundworms	Echinoderms	
Red Algae	Flatworms		
	Coelenterates		Higher Phycomycetes
Brown Algae	Sponges		

DEVELOPMENT OF MULTICELLULAR OR COENOCYTIC STRUCTURE

PROTISTA

Protozoa

Unicellular Green Algae	Amoeboid	Cilliated	Lower Phycomycetes (Chytridiales, et. al.)
Diatoms	Flagellated, (non-pigmented)	Suctoria	
Pigmented Flagellates			

DEVELOPMENT OF A NUCLEAR MEMBRANE

MONERA

Blue Green Algae	Actinomycetes
Phototropic Bacteria	Spirochaetes
Chemotropic Bacteria	Saprophytic Bacterial Types

BI. ECO. pl. 2a. 1. 69

FIGURE 2

B A food web is the interlocking pattern of food chains in an ecosystem. (Figures 3, 4) In complex natural communities, organisms whose food is obtained by the same number of steps are said to belong to the same trophic (feeding) level.

C Trophic Levels

1 First - Green plants (producers) (Figure 5) fix biochemical energy and synthesize basic organic substances. This is "primary production".

2 Second - Plant eating animals (herbivores) depend on the producer organisms for food.

3 Third - Primary carnivores, animals which feed on herbivores.

4 Fourth - Secondary carnivores feed on primary carnivores.

5 Last - Ultimate carnivores are the last or ultimate level of consumers.

D Total Assimilation

The amount of energy which flows through a trophic level is distributed between the production of biomass (living substance), and the demands of respiration (internal energy use by living organisms) in a ratio of approximately 1:10.

E Trophic Structure of the Ecosystem

The interaction of the food chain phenomena (with energy loss at each transfer) results in various communities having definite trophic structure or energy levels. Trophic structure may be measured and described either in terms of the standing crop per unit area or in terms of energy fixed per unit area per unit time at successive trophic levels. Trophic structure and function can be shown graphically by means of ecological pyramids (Figure 5).

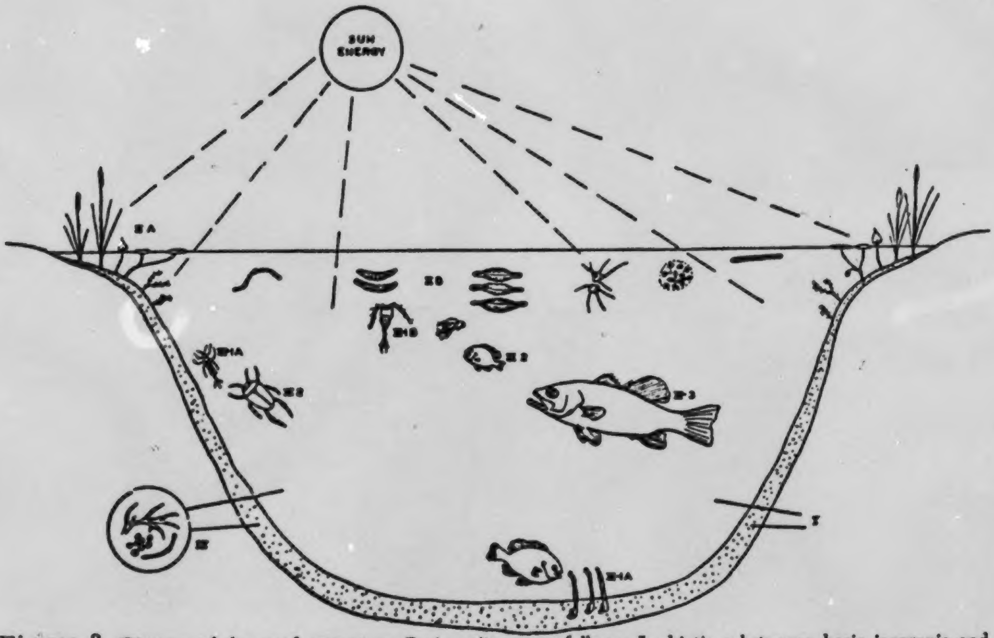

Figure 3. Diagram of the pond ecosystem. Basic units are as follows: I, abiotic substances–basic inorganic and organic compounds; IIA, producers–rooted vegetation; IIB, producers–phytoplankton; III-1A, primary consumers (herbivores)–bottom forms; III-1B, primary consumers (herbivores)–zooplankton; III-2, secondary consumers (carnivores); III-3, tertiary consumers (secondary carnivores); IV, decomposers–bacteria and fungi of decay.

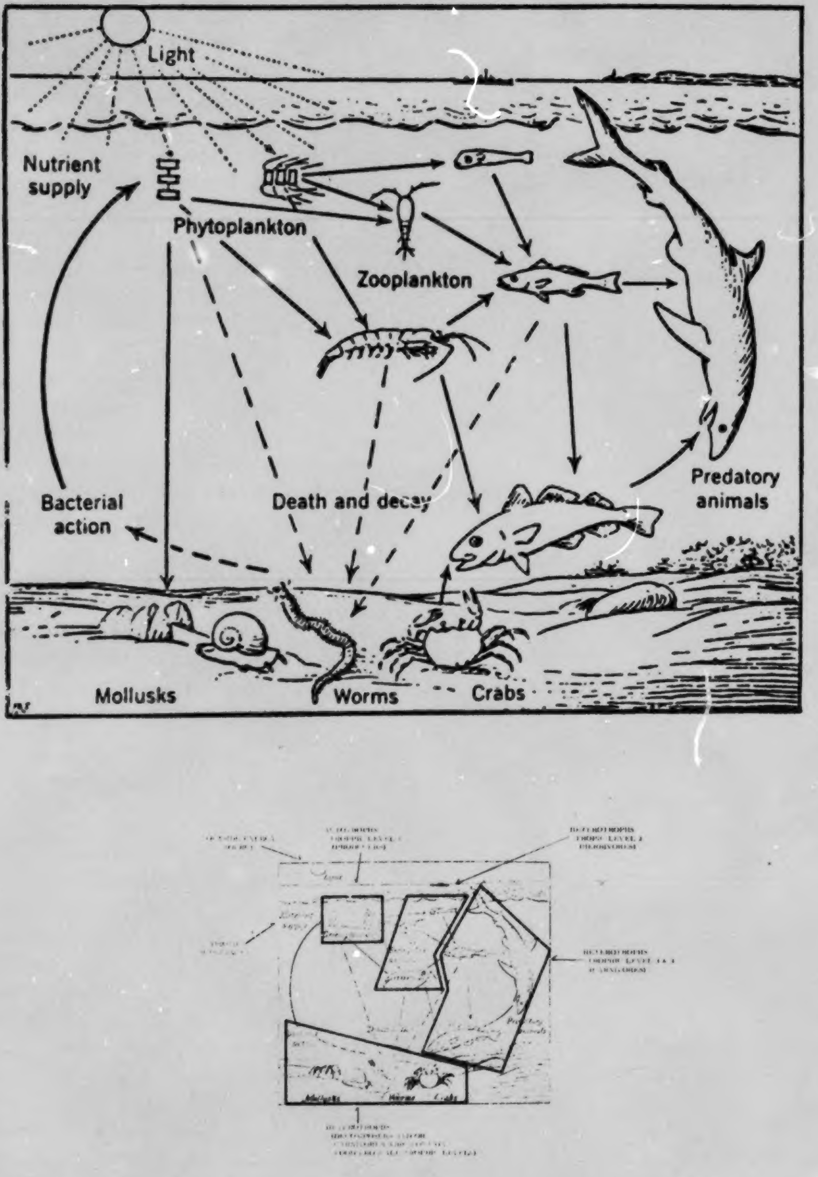
Light
Nutrient supply
Phytoplankton
Zooplankton
Predatory animals
Bacterial action
Death and decay
Mollusks
Worms
Crabs

Figure 4. A MARINE ECOSYSTEM (After Clark, 1954 and Patten, 1966)

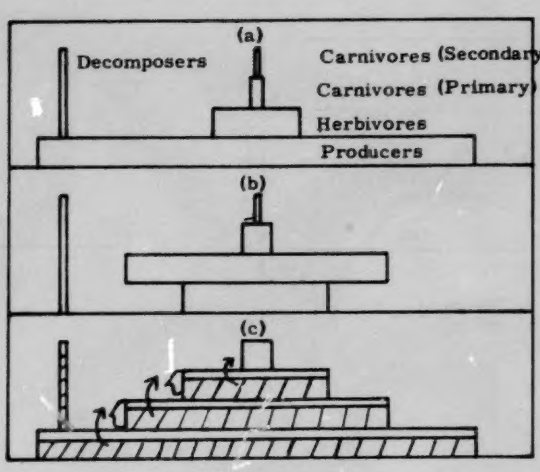

Figure 5. HYPOTHETICAL PYRAMIDS of (a) Numbers of individuals, (b) Biomass, and (c) Energy (Shading Indicates Energy Loss).

V BIOTIC COMMUNITIES

A Plankton are the macroscopic and microscopic animals, plants, bacteria, etc., floating free in the open water. Many clog filters, cause tastes, odors, and other troubles in water supplies. Eggs and larvae of larger forms are often present.

1 Phytoplankton are plant-like. These are the dominant producers of the waters, fresh and salt, "the grass of the seas".

2 Zooplankton are animal-like. Includes many different animal types, range in size from minute protozoa to gigantic marine jellyfishes.

B Periphyton (or Aufwuchs) - The communities of microscopic organisms associated with submerged surfaces of any type or depth. Includes bacteria, algae, protozoa, and other microscopic animals, and often the young or embryonic stages of algae and other organisms that normally grow up to become a part of the benthos (see below). Many planktonic types will also adhere to surfaces as periphyton, and some typical periphyton may break off and be collected as plankters.

C Benthos are the plants and animals living on, in, or closely associated with the bottom. They include plants and invertebrates.

D Nekton are the community of strong aggressive swimmers of the open waters, often called pellagic. Certain fishes, whales, and invertebrates such as shrimps and squids are included here.

E The marsh community is based on larger "higher" plants, floating and emergent. Both marine and freshwater marshes are areas of enormous biological production. Collectively known as "wetlands", they bridge the gap between the waters and the dry lands.

VI PRODUCTIVITY

A The biological resultant of all physical and chemical factors in the quantity of life that may actually be present. The ability to produce this "biomass" is often referred to as the "productivity" of a body of water. This is neither good nor bad per se. A water of low productivity is a "poor" water biologically, and also a relatively "pure" or "clean" water; hence desirable as a water supply or a bathing beach. A productive water on the other hand may be a nuisance to man or highly desirable. It is a nuisance if foul odors and/or weed-chocked waterways result, it is desirable if bumper crops of bass, catfish, or oysters are produced. Open oceans have a low level of productivity in general.

VII PERSISTENT CHEMICALS IN THE ENVIRONMENT

Increasingly complex manufacturing processes, coupled with rising industrialization, create health hazards for humans and aquatic life.

Compounds besides being toxic (acutely or chronic) may produce mutagenic effects including cancer, tumors, and teratogenicity (embryo defects). Fortunately there are tests, such as the Amis test, to screen chemical compounds for these effects.

A Metals - current levels of cadmium, lead and other substances constitute a mounting concern. Mercury pollution, as at Minimata, Japan has been fully documented.

B Pesticides

1 A pesticide and its metabolites may move through an ecosystem in many ways. Hard (pesticides which are persistent, having a long half-life in the environment includes the organochlorines, ex., DDT) pesticides ingested or otherwise borne by the target species will stay in the environment, possibly to be recycled or concentrated further through the natural action of food chains if the species is eaten. Most of the volume of pesticides do not reach their target at all.

2 Biological magnification

Initially, low levels of persistent pesticides in air, soil, and water may be concentrated at every step up the food chain. Minute aquatic organisms and scavengers, which screen water and bottom mud having pesticide levels of a few parts per billion, can accumulate levels measured in parts per million—a thousandfold increase. The sediments including fecal deposits are continuously recycled by the bottom animals.

a Oysters, for instance, will concentrate DDT 70,000 times higher in their tissues than it's concentration in surrounding water. They can also partially cleanse themselves in water free of DDT.

b Fish feeding on lower organisms build up concentrations in their visceral fat which may reach several thousand parts per million and levels in their edible flesh of hundreds of parts per million.

c Larger animals, such as fish-eating gulls and other birds, can further concentrate the chemicals. A survey on organochlorine residues in aquatic birds in the Canadian prairie provinces showed that California and ring-billed gulls were among the most contaminated. Since gulls breed in colonies, breeding population changes can be detected and related to levels of chemical contamination. Ecological research on colonial birds to monitor the effects of chemical pollution on the environment is useful.

C "Polychlorinated biphenyls" (PCB's). PCB's were used in plasticizers, asphalt, ink, paper, and a host of other products. Action was taken to curtail their release to the environment, since their effects are similar to hard pesticides. However this doesn't solve the problems of contaminated sediments and ecosystems and final fate of the PCB's still circulating.

D There are numerous other compounds which are toxic and accumulated in the ecosystem.

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Part 3. The Freshwater Environment

I INTRODUCTION

The freshwater environment as considered herein refers to those inland waters not detectably diluted by ocean waters, although the lower portions of rivers are subject to certain tidal flow effects.

Certain atypical inland waters such as saline or alkaline lakes, springs, etc., are not treated, as the main objective here is typical inland water.

All waters have certain basic biological cycles and types of interactions most of which have already been presented, hence this outline will concentrate on aspects essentially peculiar to fresh inland waters.

II PRESENT WATER QUALITY AS A FUNCTION OF THE EVOLUTION OF FRESH WATERS

A The history of a body of water determines its present condition. Natural waters have evolved in the course of geologic time into what we know today.

B Streams

In the course of their evolution, streams in general pass through four stages of development which may be called: birth, youth, maturity, and old age.

These terms or conditions may be employed or considered in two contexts: temporal, or spatial. In terms of geologic time, a given point in a stream may pass through each of the stages described below or: at any given time, these various stages of development can be loosely identified in successive reaches of a stream traveling from its headwaters to base level in ocean or major lake.

1 Establishment or birth. This might be a "dry run" or headwater stream-bed, before it had eroded down to the level of ground water. During periods of run-off after a rain or snow-melt, such a gulley would have a flow of water which might range from torrential to a mere trickle. Erosion may proceed rapidly as there is no permanent aquatic flora or fauna to stabilize streambed materials. On the other hand, terrestrial grass or forest growth may retard erosion. When the run-off has passed, however, the "streambed" is dry.

2 Youthful streams. When the streambed is eroded below the ground water level, spring or seepage water enters, and the stream becomes permanent. An aquatic flora and fauna develops and water flows the year round. Youthful streams typically have a relatively steep gradient, rocky beds, with rapids, falls, and small pools.

3 Mature streams. Mature streams have wide valleys, a developed flood plain, are deeper, more turbid, and usually have warmer water, sand, mud, silt, or clay bottom materials which shift with increase in flow. In their more favorable reaches, streams in this condition are at a peak of biological productivity. Gradients are moderate, riffles or rapids are often separated by long pools.

4 In old age, streams have approached geologic base level, usually the ocean. During flood stage they scour their beds and deposit materials on the flood plain which may be very broad and flat. During normal flow the channel is refilled and many shifting bars are developed. Meanders and ox-bow lakes are often formed.

(Under the influence of man this pattern may be broken up, or temporarily interrupted. Thus an essentially "youthful" stream might take on some of the characteristics of a "mature" stream following soil erosion, organic enrichment, and increased surface runoff. Correction of these conditions might likewise be followed by at least a partial reversion to the "original" condition).

C Lakes and Reservoirs

Geological factors which significantly affect the nature of either a stream or lake include the following:

1 The geographical location of the drainage basin or watershed.

2 The size and shape of the drainage basin.

3 The general topography, i.e., mountainous or plains.

4 The character of the bedrocks and soils.

5 The character, amount, annual distribution, and rate of precipitation.

6 The natural vegetative cover of the land is, of course, responsive to and responsible for many of the above factors and is also severely subject to the whims of civilization. This is one of the major factors determining run-off versus soil absorption, etc.

D Lakes have a developmental history which somewhat parallels that of streams. This process is often referred to as natural eutrophication.

1 The methods of formation vary greatly, but all influence the character and subsequent history of the lake.

In glaciated areas, for example, a huge block of ice may have been covered with till. The glacier retreated, the ice melted, and the resulting hole became a lake. Or, the glacier may actually scoop out a hole. Landslides may dam valleys, extinct volcanoes may collapse, etc., etc.

2 Maturing or natural eutrophication of lakes.

a If not already present shoal areas are developed through erosion and deposition of the shore material by wave action and undertow.

b Currents produce bars across bays and thus cut off irregular areas.

c Silt brought in by tributary streams settles out in the quiet lake water

d Algae grow attached to surfaces, and floating free as plankton. Dead organic matter begins to accumulate on the bottom.

e Rooted aquatic plants grow on shoals and bars, and in doing so cut off bays and contribute to the filling of the lake.

f Dissolved carbonates and other materials are precipitated in the deeper portions of the lake in part through the action of plants.

g When filling is well advanced, mats of sphagnum moss may extend outward from the shore. These mats are followed by sedges and grasses which finally convert the lake into a marsh.

3 Extinction of lakes. After lakes reach maturity, their progress toward filling up is accelerated. They become extinct through:

a The downcutting of the outlet.

b Filling with detritus eroded from the shores or brought in by tributary streams.

c Filling by the accumulation of the remains of vegetable materials growing in the lake itself.
(Often two or three processes may act concurrently)

III PRODUCTIVITY IN FRESH WATERS

A Fresh waters in general and under natural conditions by definition have a lesser supply of dissolved substances than marine waters, and thus a lesser basic potential for the growth of aquatic organisms. By the same token, they may be said to be more sensitive to the addition of extraneous materials (pollutants, nutrients, etc.) The following notes are directed toward natural geological and other environmental factors as they affect the productivity of fresh waters.

B Factors Affecting Stream Productivity (See Table 1)

TABLE 1

EFFECT OF SUBSTRATE ON STREAM PRODUCTIVITY*

(The productivity of sand bottoms is taken as 1)

Bottom Material	Relative Productivity
Sand	1
Marl	6
Fine Gravel	9
Gravel and silt	14
Coarse gravel	32
Moss on fine gravel	89
Fissidens (moss) on coarse gravel	111
Ranunculus (water buttercup)	194
Watercress	301
Elodea (waterweed)	452

*Selected from Tarzwell 1937

To be productive of aquatic life, a stream must provide adequate nutrients, light, a suitable temperature, and time for growth to take place.

1 Youthful streams, especially on rock or sand substrates are low in essential nutrients. Temperatures in mountainous regions are usually low, and due to the steep gradient, time for growth is short. Although ample light is available, growth of true plankton is thus greatly limited.

2 As the stream flows toward a more "mature" condition, nutrients tend to accumulate, and gradient diminishes and so time of flow increases, temperature tends to increase, and plankton flourish.

Should a heavy load of inert silt develop on the other hand, the turbidity would reduce the light penetration and consequently the general plankton production would diminish.

3 As the stream approaches base level (old age) and the time available for plankton growth increases, the balance between turbidity, nutrient levels, and temperature and other seasonal conditions, determines the overall productivity.

C Factors Affecting the Productivity of lakes (See Table 2)

1 The size, shape, and depth of the lake basin. Shallow water is more productive than deeper water since more light will reach the bottom to stimulate rooted plant growth. As a corollary, lakes with more shoreline, having more shallow water, are in general more productive. Broad shallow lakes and reservoirs have the greatest production potential (and hence should be avoided for water supplies).

TABLE 2

EFFECT OF SUBSTRATE ON LAKE PRODUCTIVITY *

(The productivity of sand bottoms is taken as 1)

Bottom Material	Relative Productivity
Sand	1
Pebbles	4
Clay	8
Flat rubble	9
Block rubble	11
Shelving rock	77

* Selected from Tarzwell 1937

2 Hard waters are generally more productive than soft waters as there are more plant nutrient minerals available. This is often greatly influenced by the character of the soil and rocks in the watershed and the quality and quantity of ground water entering the lake. In general, pH ranges of 6.8 to 8.2 appear to be most productive.

3 Turbidity reduces productivity as light penetration is reduced.

4 The presence or absence of thermal stratification with its semi-annual turnovers affects productivity by distributing nutrients throughout the water mass.

5 Climate, temperature, prevalence of ice and snow, are also of course important.

D Factors Affecting the Productivity of Reservoirs

1 The productivity of reservoirs is governed by much the same principles as that of lakes, with the difference that the water level is much more under the control of man. Fluctuations in water level can be used to deliberately increase or decrease productivity. This can be demonstrated by a comparison of the TVA reservoirs which practice a summer drawdown with some of those in the west where a winter drawdown is the rule.

2 The level at which water is removed from a reservoir is important to the productivity of the stream below. The hypolimnion may be anaerobic while the epilimnion is aerobic, for example, or the epilimnion is poor in nutrients while the hypolimnion is relatively rich.

3 Reservoir discharges also profoundly affect the DO, temperature, and turbidity in the stream below a dam. Too much fluctuation in flow may permit sections of the stream to dry, or provide inadequate dilution for toxic waste.

IV CULTURAL EUTROPHICATION

A The general processes of natural eutrophication, or natural enrichment and productivity have been briefly outlined above.

B When the activities of man speed up these enrichment processes by introducing unnatural quantities of nutrients (sewage, etc.) the result is often called cultural eutrophication. This term is often extended beyond its original usage to include the enrichment (pollution) of streams, estuaries, and even oceans, as well as lakes.

V CLASSIFICATION OF LAKES AND RESERVOIRS

A The productivity of lakes and impoundments is such a conspicuous feature that it is often used as a convenient means of classification.

1 Oligotrophic lakes are the younger, less productive lakes, which are deep, have clear water, and usually support Salmonoid fishes in their deeper waters.

2 Eutrophic lakes are more mature, more turbid, and richer. They are usually shallower. They are richer in dissolved solids; N, P, and Ca are abundant. Plankton is abundant and there is often a rich bottom fauna.

3 Dystrophic lakes, such as bog lakes, are low in Ph, water yellow to brown, dissolved solids, N, P, and Ca scanty but humic materials abundant, bottom fauna and plankton poor, and fish species are limited.

B Reservoirs may also be classified as storage, and run of the river.

1 Storage reservoirs have a large volume in relation to their inflow.

2 Run of the river reservoirs have a large flow-through in relation to their storage value.

C According to location, lakes and reservoirs may be classified as polar, temperate, or tropical. Differences in climatic and geographic conditions result in differences in their biology.

VI SUMMARY

A A body of water such as a lake, stream, or estuary represents an intricately balanced system in a state of dynamic equilibrium. Modification imposed at one point in the system automatically results in compensatory adjustments at associated points.

B The more thorough our knowledge of the entire system, the better we can judge where to impose control measures to achieve a desired result.

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Part 4. The Marine Environment and its Role in the Total Aquatic Environment

I INTRODUCTION

A The marine environment is arbitrarily defined as the water mass extending beyond the continental land masses, including the plants and animals harbored therein. This water mass is large and deep, covering about 70 percent of the earth's surface and being as deep as 7 miles. The salt content averages about 35 parts per thousand. Life extends to all depths.

B The general nature of the water cycle on earth is well known. Because the largest portion of the surface area of the earth is covered with water, roughly 70 percent of the earth's rainfall is on the seas. (Figure 1)

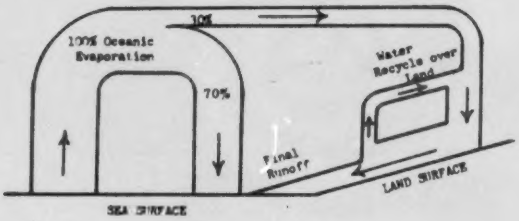

Figure 1. THE WATER CYCLE

Since roughly one third of the rain which falls on the land is again recycled through the atmosphere (see Figure 1 again), the total amount of water washing over the earth's surface is significantly greater than one third of the total world rainfall. It is thus not surprising to note that the rivers which finally empty into the sea carry a disproportionate burden of dissolved and suspended solids picked up from the land. The chemical composition of this burden depends on the composition of the rocks and soils through which the river flows, the proximity of an ocean, the direction of prevailing winds, and other factors. This is the substance of geological erosion. (Table 1)

TABLE 1

PERCENTAGE COMPOSITION OF THE MAJOR IONS OF TWO STREAMS AND SEA WATER

(Data from Clark, F.W., 1924, "The Composition of River and Lake Waters of the United States", U.S. Geol. Surv., Prof. Paper No. 135; Harvey, H.W., 1957, "The Chemistry and Fertility of Sea Waters", Cambridge University Press, Cambridge)

Ion	Delaware River at Lambertville, N.J.	Rio Grande at Laredo, Texas	Sea Water
Na	6.70	14.78	30.4
K	1.46	.85	1.1
Ca	17.49	13.73	1.16
Mg	4.81	3.03	3.7
Cl	4.23	21.65	55.2
SO_4	17.49	30.10	[illegible]
CO_3	32.95	11.55	$+HCO_3$ 0.35

C For this presentation, the marine environment will be (1) described using an ecological approach, (2) characterized ecologically by comparing it with freshwater and estuarine environments, and (3) considered as a functional ecological system (ecosystem).

II FRESHWATER, ESTUARINE, AND MARINE ENVIRONMENTS

Distinct differences are found in physical, chemical, and biotic factors in going from a freshwater to an oceanic environment. In general, environmental factors are more constant in freshwater (rivers) and oceanic environments than in the highly variable and harsh environments of estuarine and coastal waters. (Figure 2)

A Physical and Chemical Factors

Rivers, estuaries, and oceans are compared in Figure 2 with reference to the relative instability (or variation) of several important parameters. In the oceans, it will be noted, very little change occurs in any parameter. In rivers, while "salinity" (usually referred to as "dissolved solids") and temperature (accepting normal seasonal variations) change little, the other four parameters vary considerably. In estuaries, they all change.

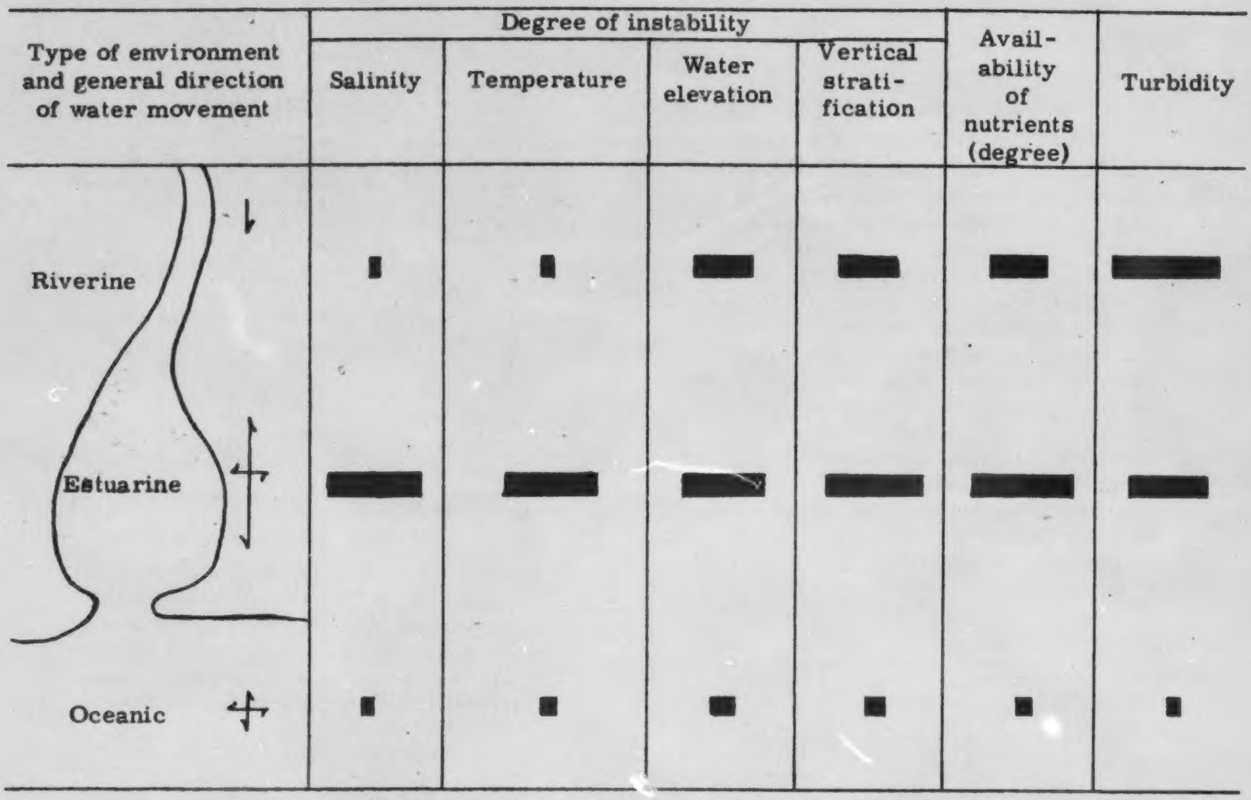

Figure 2. RELATIVE VALUES OF VARIOUS PHYSICAL AND CHEMICAL FACTORS FOR RIVER, ESTUARINE, AND OCEANIC ENVIRONMENTS

B Biotic Factors

1 A complex of physical and chemical factors determine the biotic composition of an environment. In general, the number of species in a rigorous, highly variable environment tends to be less than the number in a more stable environment (Hedgpeth, 1966).

2 The dominant animal species (in terms of total biomass) which occur in estuaries are often transient, spending only a part of their lives in the estuaries. This results in better utilization of a rich environment.

C Zones of the Sea

The nearshore environment is often classified in relation to tide level and water depth. The nearshore and offshore oceanic regions together, are often classified with reference to light penetration and water depth. (Figure 3)

1 Neritic - Relatively shallow-water zone which extends from the high-tide mark to the edge of the continental shelf.

MARINE ECOLOGY

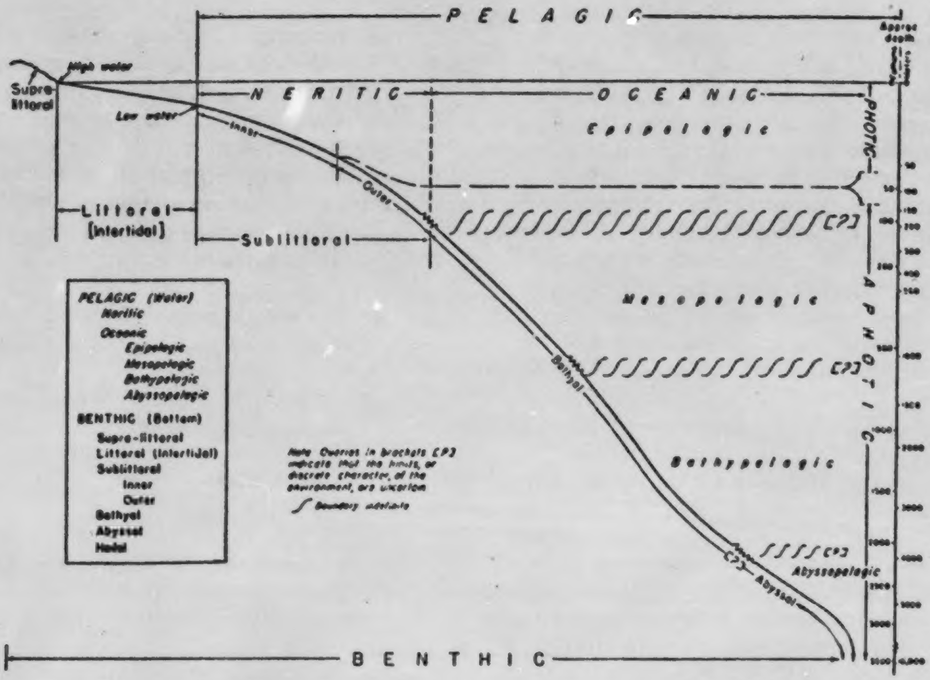
PELAGIC
Approx depth
High water
Supra-littoral
Low water
NERITIC
OCEANIC
Epipelagic
PHOTIC
Inner
Outer
Littoral [Intertidal]
Sublittoral
[?]
Mesopelagic
APHOTIC
Bathyal
[?]
Bathypelagic
[?]
Abyssopelagic
Abyssal
BENTHIC
PELAGIC (Water)
Neritic
Oceanic
Epipelagic
Mesopelagic
Bathypelagic
Abyssopelagic
BENTHIC (Bottom)
Supra-littoral
Littoral (Intertidal)
Sublittoral
Inner
Outer
Bathyal
Abyssal
Hadal
Note: Queries in brackets [?] indicate that the limits, or discrete character, of the environment, are uncertain
Boundary undulate

FIGURE 3—*Classification of marine environments*

a Stability of physical factors is intermediate between estuarine and oceanic environments.

b Phytoplankters are the dominant producers but in some locations attached algae are also important as producers.

c The animal consumers are zooplankton, nekton, and benthic forms.

2 Oceanic - The region of the ocean beyond the continental shelf. Divided into three parts, all relatively poorly populated compared to the neritic zone.

a Euphotic zone - Waters into which sunlight penetrates (often to the bottom in the neritic zone). The zone of primary productivity often extends to 600 feet below the surface.

1) Physical factors fluctuate less than in the neritic zone.

2) Producers are the phytoplankton and consumers are the zooplankton and nekton.

b Bathyal zone - From the bottom of the euphotic zone to about 2000 meters.

1) Physical factors relatively constant but light is absent.

2) Producers are absent and consumers are scarce.

c Abyssal zone - All the sea below the bathyal zone.

1) Physical factors more constant than in bathyal zone.

2) Producers absent and consumers even less abundant than in the bathyal zone.

III SEA WATER AND THE BODY FLUIDS

A Sea water is a remarkably suitable environment for living cells, as it contains all of the chemical elements essential to the growth and maintenance of plants and animals. The ratio and often the concentration of the major salts of sea water are strikingly similar in the cytoplasm and body fluids of marine organisms. This similarity is also evident, although modified somewhat in the body fluids of fresh water and terrestrial animals. For example, sterile sea water may be used in emergencies as a substitute for blood plasma in man.

B Since marine organisms have an internal salt content similar to that of their surrounding medium (isotonic condition) osmoregulation poses no problem. On the other hand, fresh water organisms are hypertonic (osmotic pressure of body fluids is higher than that of the surrounding water). Hence, fresh water animals must constantly expend more energy to keep water out (i.e., high osmotic pressure fluids contain more salts, the action being then to dilute this concentration with more water).

1 Generally, marine invertebrates are narrowly poikilosmotic, i.e., the salt concentration of the body fluids changes with that of the external medium. This has special significance in estuarine situations where salt concentrations of the water often vary considerably in short periods of time.

2 Marine bony fish (teleosts) have lower salt content internally than the external environment (hypotonic). In order to prevent dehydration, water is ingested and salts are excreted through special cells in the gills.

IV FACTORS AFFECTING THE DISTRIBUTION OF MARINE AND ESTUARINE ORGANISMS

A Salinity. Salinity is the single most constant and controlling factor in the marine environment, probably followed by temperature. It ranges around 35,000 mg. per liter, or "35 parts per thousand" (symbol: 35‰) in the language of the oceanographer. While variations in the open ocean are relatively small, salinity decreases rapidly as one approaches shore and proceeds through the estuary and up into fresh water with a salinity of "0 ‰ (see Figure 2)

B Salinity and temperature as limiting factors in ecological distribution.

1 Organisms differ in the salinities and temperatures in which they prefer to live, and in the variabilities of these parameters which they can tolerate. These preferences and tolerances often change with successive life history stages, and in turn often dictate where the organisms live: their "distribution."

2 These requirements or preferences often lead to extensive migrations of various species for breeding, feeding, and growing stages. One very important result of this is that an estuarine environment is an absolute necessity for over half of all coastal commercial and sport related species of fishes and invertebrates, for either all or certain portions of their life histories. (Part V, figure 8)

3 The Greek word roots "eury" (meaning wide) and "steno" (meaning narrow) are customarily combined with such words as "haline" for salt, and "thermal" for temperature, to give us "euryhaline" as an adjective to characterize an organism able to tolerate a wide range of salinity, for example; or "stenothermal" meaning one which cannot stand much change in temperature. "Meso-" is a prefix indicating an intermediate capacity.

C Marine, estuarine, and fresh water organisms. (See Figure 4)

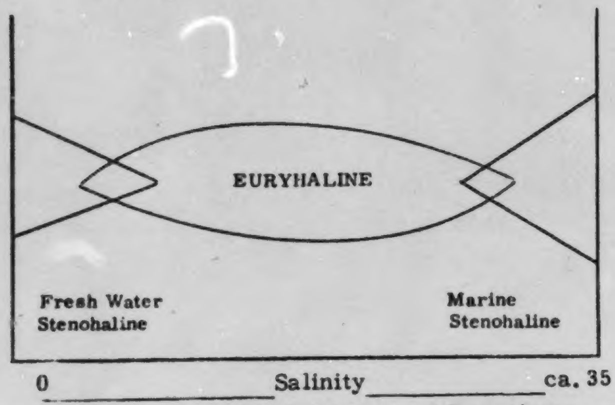

Figure 4. Salinity Tolerance of Organisms

1 Offshore marine organisms are, in general, both stenohaline and stenothermal unless, as noted above, they have certain life history requirements for estuarine conditions.

2 Fresh water organisms are also stenohaline, and (except for seasonal adaptation) meso- or stenothermal. (Figure 2)

3 Indigenous or native estuarine species that normally spend their entire lives in the estuary are relatively few in number. (See Figure 5). They are generally meso- or euryhaline and meso- or eurythermal.

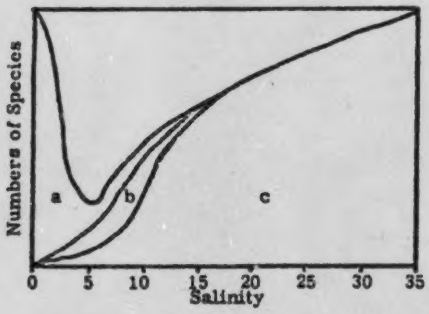

Figure 5. DISTRIBUTION OF ORGANISMS IN AN ESTUARY

a Euryhaline, freshwater
b Indigenous, estuarine, (mesohaline)
c Euryhaline, marine

4 Some well known and interesting examples of migratory species which change their environmental preferences with the life history stage include the shrimp (mentioned above), striped bass, many herrings and relatives, the salmons, and many others. None are more dramatic than the salmon hordes which lay their eggs in freshwater streams, migrate far out to sea to feed and grow, then return to the stream where they hatched to lay their own eggs before dying.

5 Among euryhaline animals landlocked (trapped), populations living in lowered salinities often have a smaller maximum size than individuals of the same species living in more saline waters. For example, the lamprey (Petromyzon marinus) attains a length of 30 - 36" in the sea, while in the Great Lakes the length is 18 - 24".

Usually the larvae of aquatic organisms are more sensitive to changes in salinity than are the adults. This characteristic both limits and dictates the distribution and size of populations.

D The effects of tides on organisms.

1 Tidal fluctuations probably subject the benthic or intertidal populations to the most extreme and rapid variations of environmental stress encountered in any aquatic habitat. Highly specialized communities have developed in this zone, some adapted to the rocky surf zones of the open coast, others to the muddy inlets of protected estuaries. Tidal reaches of fresh water rivers, sandy beaches, coral reefs and mangrove swamps in the tropics; all have their own floras and faunas. All must emerge and flourish when whatever water there is rises and covers or tears at them, all must collapse or retract to endure drying, blazing tropical sun, or freezing arctic ice during the low tide interval. Such a community is depicted in Figure 6.

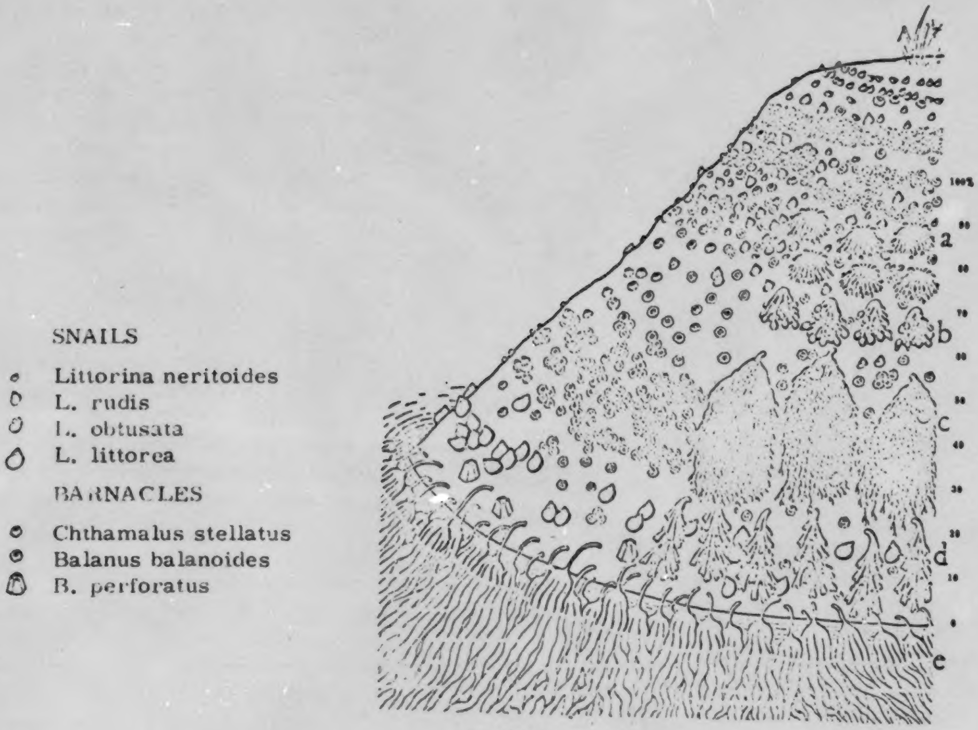
SNAILS
Littorina neritoides
L. rudis
L. obtusata
L. littorea
BARNACLES
Chthamalus stellatus
Balanus balanoides
B. perforatus
100%
a
b
c
d
e

Figure 6

Zonation of plants, snails, and barnacles on a rocky shore. While this diagram is based on the situation on the southwest coast of England, the general idea of zonation may be applied to any temperate rocky ocean shore, though the species will differ. The gray zone consists largely of lichens. At the left is the zonation of rocks with exposure too extreme to support algae; at the right, on a less exposed situation, the animals are mostly obscured by the algae. Figures at the right hand margin refer to the percent of time that the zone is exposed to the air, i. e., the time that the tide is out. Three major zones can be recognized: the Littorina zone (above the gray zone); the Balanoid zone (between the gray zone and the laminarias); and the Laminaria zone. a. Pelvetia canaliculata; b. Fucus spiralis; c. Ascophyllum nodosum; d. Fucus serratus; e. Laminaria digitata. (Based on Stephenson)

V FACTORS AFFECTING THE PRODUCTIVITY OF THE MARINE ENVIRONMENT

A The sea is in continuous circulation. Without circulation, nutrients of the ocean would eventually become a part of the bottom and biological production would cease. Generally, in all oceans there exists a warm surface layer which overlies the colder water and forms a two-layer system of persistent stability. Nutrient concentration is usually greatest in the lower zone. Wherever a mixing or disturbance of these two layers occurs biological production is greatest.

B The estuaries are also a mixing zone of enormous importance. Here the fertility washed off the land is mingled with the nutrient capacity of seawater, and many of the would's most productive waters result.

C When man adds his cultural contributions of sewage, fertilizer, silt or toxic waste, it is no wonder that the dynamic equilibrium of the ages is rudely upset, and the environmentalist cries, "See what man hath wrought"!

ACKNOWLEDGEMENT:

This outline contains selected material from other outlines prepared by C. M. Tarzwell, Charles L. Brown, Jr., C. G. Gunnerson, W. Lee Trent, W. B. Cooke, B. H. Ketchum, J. K. McNulty, J. L. Taylor, R. M. Sinclair, and others.

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Part 5: Wetlands

I INTRODUCTION

A Broadly defined, wetlands are areas which are "to wet to plough but too thick to flow." The soil tends to be saturated with water, salt or fresh, and numerous channels or ponds of shallow or open water are common. Due to ecological features too numerous and variable to list here, they comprise in general a rigorous (highly stressed) habitat, occupied by a small relatively specialized indigenous (native) flora and fauna.

B They are prodigiously productive however, and many constitute an absolutely essential habitat for some portion of the life history of animal forms generally recognized as residents of other habitats (Figure 8). This is particularly true of tidal marshes as mentioned below.

C Wetlands in toto comprise a remarkably large proportion of the earth's surface, and the total organic carbon bound in their mass constitutes an enormous sink of energy.

D Since our main concern here is with the "aquatic" environment, primary emphasis will be directed toward a description of wetlands as the transitional zone between the waters and the land, and how their desecration by human culture spreads degradation in both directions.

II TIDAL MARSHES AND THE ESTUARY

A "There is no other case in nature, save in the coral reefs, where the adjustment of organic relations to physical condition is seen in such a beautiful way as the balance between the growing marshes and the tidal streams by which they are at once nourished and worn away." (Shaler, 1886)

B Estuarine pollution studies are usually devoted to the dynamics of the circulating water, its chemical, physical, and biological parameters, bottom deposits, etc.

C It is easy to overlook the intimate relationships which exist between the bordering marshland, the moving waters, the tidal flats, subtidal deposition, and seston whether of local, oceanic, or riverine origin.

D The tidal marsh (some inland areas also have salt marshes) is generally considered to be the marginal areas of estuaries and coasts in the intertidal zone, which are dominated by emergent vegetation. They generally extend inland to the farthest point reached by the spring tides, where they merge into freshwater swamps and marshes (Figure 1). They may range in width from nonexistent on rocky coasts to many kilometers.

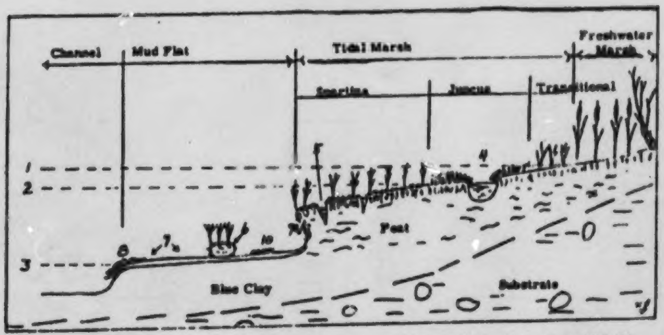

Figure 1. Zonation in a positive New England estuary. 1. Spring tide level, 2. Mean high tide, 3. Mean low tide, 4. Bog hole, 5. Ice cleavage pool, 6. Chunk of *Spartina* turf deposited by ice, 7. Organic ooze with associated community, 8. eelgrass (*Zostera*), 9. Ribbed mussels (modiolus)-clam (*mya*) - mud snail (*Nassa*) community. 10. Sea lettuce (*Ulva*)

III MARSH ORIGINS AND STRUCTURES

A In general, marsh substrates are high in organic content, relatively low in minerals and trace elements. The upper layers bound together with living roots called turf, underlaid by more compacted peat type material.

1 Rising or eroding coastlines may expose peat from ancient marsh growth to wave action which cuts into the soft peat rapidly (Figure 2).

Such banks are likely to be cliff-like, and are often undercut. Chunks of peat are often found lying about on harder substrate below high tide line. If face of cliff is well above high water, overlying vegetation is likely to be typically terrestrial of the area. Marsh type vegetation is probably absent.

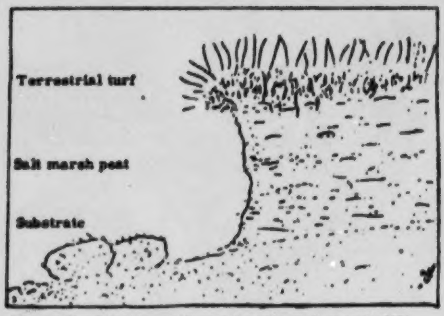

Figure 2. Diagrammatic section of eroding peat cliff

2 Low lying deltaic, or sinking coastlines, or those with low energy wave action are likely to have active marsh formation in progress. Sand dunes are also common in such areas (Figure 3). General coastal configuration is a factor.

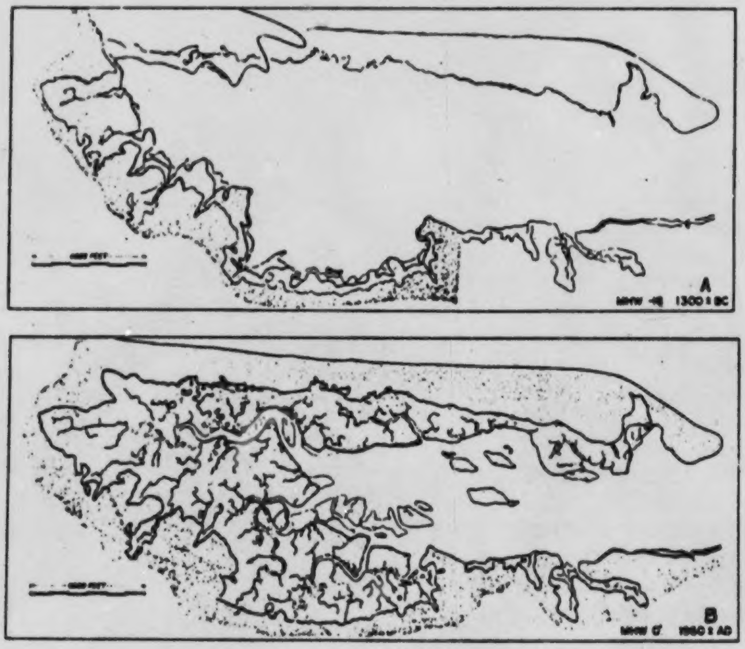

Figure 3

Development of a Massachusetts Marsh since 1300 BC, involving an 18 foot rise in water level. Shaded area indicates sand dunes. Note meandering marsh tidal drainage. A: 1300 BC, B: 1950 AD.

a Rugged or precipitous coasts or slowly rising coasts, typically exhibit narrow shelves, sea cliffs, fjords, massive beaches, and relatively less marsh area (Figure 4). An Alaskan fjord subject to recent catastrophic subsidence and rapid deposition of glacial flour shows evidence of the recent encroachment of saline waters in the presence of recently buried trees and other terrestrial vegetation, exposure of layers of salt marsh peat along the edges of channels, and a poorly compacted young marsh turf developing at the new high water level (Figure 5).

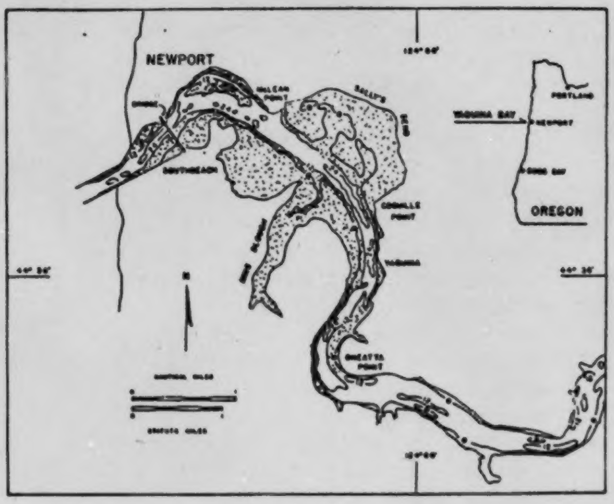

Figure 4 A River Mouth on a Slowly Rising Coast. Note absence of deltaic development and relatively little marshland, although mud flats stippled are extensive.

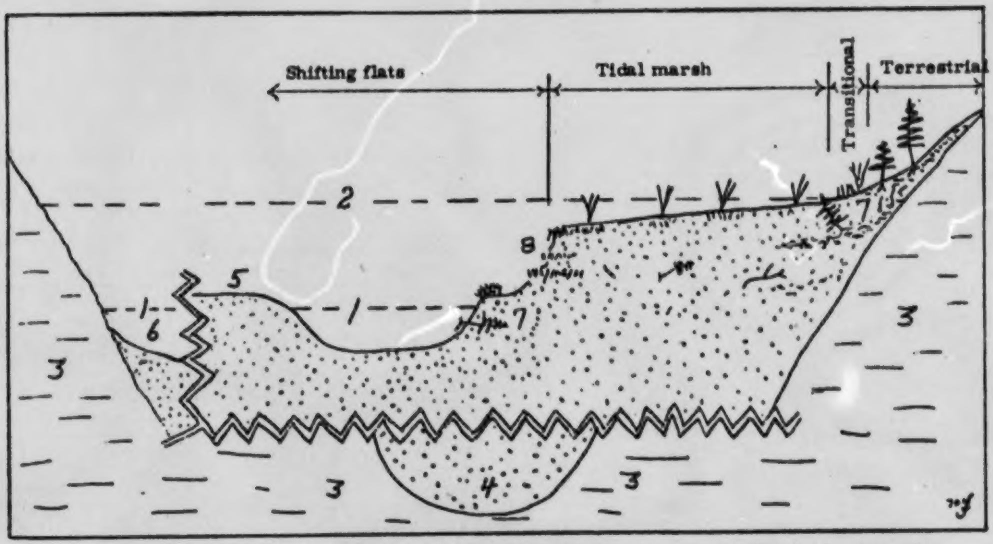

Figure 5 Some general relationships in a northern fjord with a rising water level. 1. mean low water, 2. maximum high tide, 3. Bedrock, 4. Glacial flour to depths in excess of 400 meters, 5. Shifting flats and channels, 6. Channel against bedrock, 7. Buried terrestrial vegetation, 8. Outcroppings of salt marsh peat.

b Low lying coastal plains tend to be fringed by barrier islands, broad estuaries and deltas, and broad associated marshlands (Figure 3). Deep tidal channels fan out through innumerable branching and often interconnecting rivulets. The intervening grassy plains are essentially at mean high tide level.

c Tropical and subtropical regions such as Florida, the Gulf Coast, and Central America, are frequented by mangrove swamps. This unique type of growth is able to establish itself in shallow water and move out into progressively deeper areas (Figure 6). The strong deeply embedded roots enable the mangrove to resist considerable wave action at times, and the tangle of roots quickly accumulates a deep layer of organic sediment. Mangroves in the south may be considered to be roughly the equivalent of the Spartina marsh grass in the north as a land builder. When fully developed, a mangrove swamp is an impenetrable thicket of roots over the tidal flat affording shelter to an assortment of semi-aquatic organisms such as various molluscs and crustaceans, and providing access from the nearby land to predaceous birds, reptiles, and mammals. Mangroves are not restricted to estuaries, but may develop out into shallow oceanic lagoons, or upstream into relatively fresh waters.

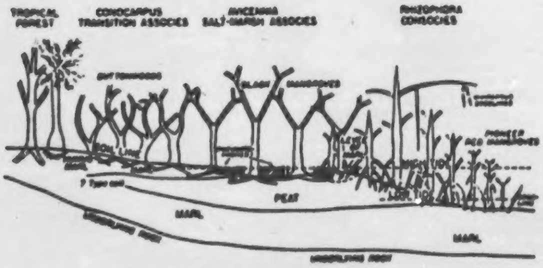

Figure 6 Diagrammatic transect of a mangrove swamp showing transition from marine to terrestrial habitat.

IV PRODUCTIVITY OF WETLANDS

A Measuring the productivity of grasslands is not easy, because today grass is seldom used directly as such by man. It is thus usually expressed as production of meat, milk, or in the case of salt marshes, the total crop of animals that obtain food per unit of area. The primary producer in a tidal marsh is the marsh grass, but very little of it is used by man as grass. (Table 1)

The nutritional analysis of several marsh grasses as compared to dry land hay is shown in Table 2.

TABLE 1. General Orders of Magnitude of Gross Primary Productivity in Terms of Dry Weight of Organic Matter Fixed Annually

Ecosystem	gms/M^2/year (grams/square meters/year)	lbs/acre/year
Land deserts, deep oceans	Tens	Hundreds
Grasslands, forests, eutrophic lakes, ordinary agriculture	Hundreds	Thousands
Estuaries, deltas, coral reefs, intensive agriculture (sugar cane, rice)	Thousands	Ten-thousands

TABLE 2. Analyses of Some Tidal Marsh Grasses

T/A	Percentage Composition					
Dry Wt.	Protein	Fat	Fiber	Water	Ash	N-free Extract
Distichlis spicata (pure stand, dry)						
2.8	5.3	1.7	32.4	8.2	6.7	45.5
Short *Spartina alterniflora* and *Salicornia europaea* (in standing water)						
1.2	7.7	2.5	31.1	8.8	12.0	37.7
Spartina alterniflora (tall, pure stand in standing water)						
3.5	7.6	2.0	29.0	8.3	15.5	37.3
Spartina patens (pure stand, dry)						
3.2	6.0	2.2	30.0	8.1	9.0	44.5
Spartina alterniflora and *Spartina patens* (mixed stand, wet)						
3.4	6.8	1.9	29.8	8.1	10.4	42.8
Spartina alterniflora (short, wet)						
2.2	8.8	2.4	30.4	8.7	13.3	36.3
Comparable Analyses for Hay						
1st cut	6.0	2.0	36.2	6.7	4.2	44.9
2nd cut	13.0	3.7	28.5	10.4	5.9	38.5

Analyses performed by Roland W. Gilbert, Department of Agricultural Chemistry, U.R.I.

B The actual utilization of marsh grass is accomplished primarily by its decomposition and ingestion by micro organisms. (Figure 7) A small quantity of seeds and solids is consumed directly by birds.

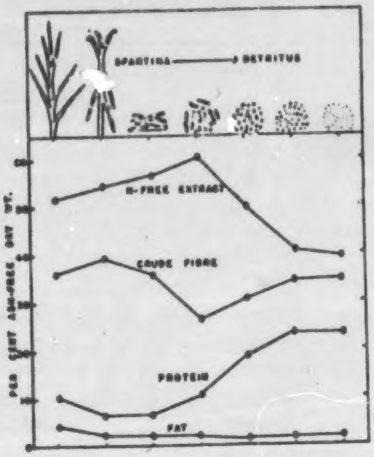

Figure 7 The nutritive composition of successive stages of decomposition of Spartina marsh grass, showing increase in protein and decrease in carbohydrate with increasing age and decreasing size of detritus particles.

1 The quantity of micro invertebrates which thrive on this wealth of decaying marsh has not been estimated, nor has the actual production of small indigenous fishes and invertebrates such as the top minnows (Fundulus), or the mud snails (Nassa), and others.

2 Many forms of oceanic life migrate into the estuaries, especially the marsh areas, for important portions of their life histories as is mentioned elsewhere (Figure 8). It has been estimated that in excess of 60% of the marine commercial and sport fisheries are estuarine or marsh dependent in some way.

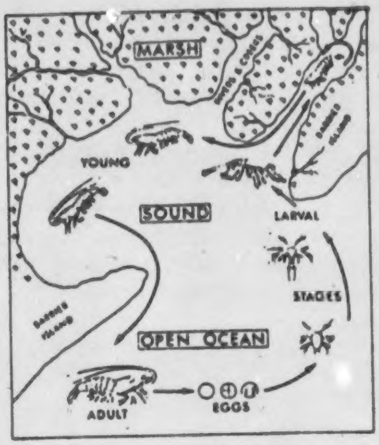

Figure 8 Diagram of the life cycle of white shrimp (after Anderson and Lunz 1965).

3 An effort to make an indirect estimate of productivity in a Rhode Island marsh was made on a single August day by recording the numbers and kinds of birds that fed on a relatively small area (Figure 9). Between 700 and 1000 wild birds of 12 species, ranging from 100 least sandpipers to uncountable numbers of seagulls were counted. One food requirement estimate for three-pound poultry in the confined inactivity of a poultry yard is approximately one ounce per pound of bird per day.

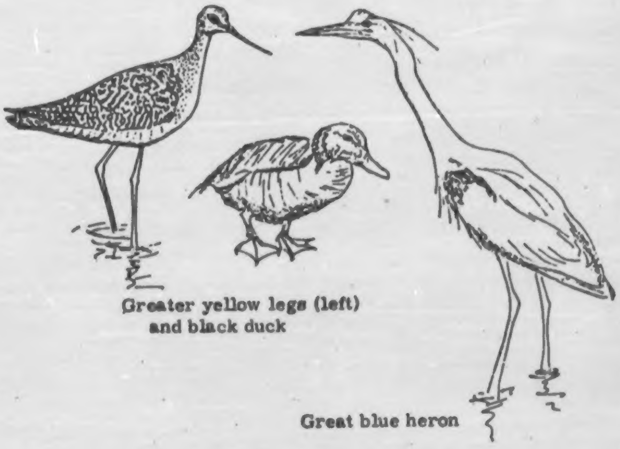

Figure 9 Some Common Marsh Birds

One-hundred black bellied plovers at approximately ten ounces each would weigh on the order of sixty pounds. At the same rate of food consumption, this would indicate nearly four pounds of food required for this species alone. The much greater activity of the wild birds would obviously greatly increase their food requirements, as would their relatively smaller size.

Considering the range of foods consumed, the sizes of the birds, and the fact that at certain seasons, thousands of migrating ducks and others pause to feed here, the enormous productivity of such a marsh can be better understood.

V INLAND BOGS AND MARSHES

A Much of what has been said of tidal marshes also applies to inland wetlands. As was mentioned earlier, not all inland swamps are salt-free, any more than all marshes affected by tidal rythms are saline.

B The specificity of specialized floras to particular types of wetlands is perhaps more spectacular in freshwater wetlands than in the marine, where Juncus, Spartina, and Mangroves tend to dominate.

1 Sphagnum, or peat moss, is probably one of the most widespead and abundant wetland plants on earth. Deevey (1958) quotes an estimate that there is probably upwards of 223 billions (dry weight) of tons of peat in the world today, derived during recent geologic time from Sphagnum bogs. Particularly in the northern regions, peat moss tends to overgrow ponds and shallow depressions, eventually forming the vast tundra plains and moores of the north.

2 Long lists of other bog and marsh plants might be cited, each with its own special requirements, topographical, and geographic distribution, etc. Included would be the familiar cattails, spike rushes, cotton grasses, sedges, trefoils, alders, and many, many others.

C Types of inland wetlands.

1 As noted above (Cf: Figure 1) tidal marshes often merge into freshwater marshes and bayous. Deltaic tidal swamps and marshes are often saline in the seaward portion, and fresh in the landward areas.

2 River bottom wetlands differ from those formed from lakes, since wide flood plains subject to periodic inundation are the final stages of the erosion of river valleys, whereas lakes in general tend to be eliminated by the geologic processes of natural eutrophication often involving Sphagnum and peat formation. Riverbottom marshes in the southern United States, with favorable climates, have luxurient growths such as the canebrake of the lower Mississippi, or a characteristic timber growth such as cypress.

3 Although bird life is the most conspicuous animal element in the fauna (Cf: Figure 9), many mammals, such as muskrats, beavers, otters, and others are also marsh-oriented. (Figure 12)

Figure 12 Otter

VI POLLUTION

A No single statement can summarize the effects of pollution on marshlands as distinct from effects noted elsewhere on other habitats.

B Reduction of Primary Productivity

The primary producers in most wetlands are the grasses and peat mosses. Production may be reduced or eliminated by:

1 Changes in the water level brought about by flooding or drainage.

a Marshland areas are sometimes diked and flooded to produce fresh-water ponds. This may be for aesthetic reasons, to suppress the growth of noxious marsh inhabitating insects such as mosquitoes or biting midges, to construct an industrial waste holding pond, a thermal or a sewage stabilization pond, a "convenient" result of highway causeway construction, or other reason. The result is the elimination of an area of marsh. A small compensating border of marsh may or may not develop.

b High tidal marshes were often ditched and drained in former days to stabilize the sod for salt hay or "thatch" harvesting which was highly sought after in colonial days. This inevitably changed the character of the marsh, but it remained as essentially marshland. Conversion to outright agricultural land has been less widespread because of the necessity of diking to exclude the periodic floods or tidal incursions, and carefully timed drainage to eliminate excess precipitation. Mechanical pumping of tidal marshes has not been economical in this country, although the success of the Dutch and others in this regard is well known.

2 Marsh grasses may also be eliminated by smothering as, for example, by deposition of dredge spoils, or the spill or discharge of sewage sludge.

3 Considerable marsh area has been eliminated by industrial construction activity such as wharf and dock construction, oil well construction and operation, and the discharge of toxic brines and other chemicals.

C Consumer production (animal life) has been drastically reduced by the deliberate distribution of pesticides. In some cases, this has been aimed at nearby agricultural lands for economic crop pest control, in other cases the marshes have been sprayed or dusted directly to control noxious insects.

1 The results have been universally disastrous for the marshes, and the benefits to the human community often questionable.

2 Pesticides designed to kill nuisance insects, are also toxic to other arthropods so that in addition to the target species, such forage staples as the various scuds (amphipods), fiddler crabs, and other macroinvertebrates have either been drastically reduced or entirely eliminated in many places. For example, one familiar with fiddler crabs can traverse miles of marsh margins, still riddled with their burrows, without seeing a single live crab.

3 DDT and related compounds have been "eaten up the food chain" (biological magnification effect) until fish eating and other predatory birds such as herons and egrets (Figure 9), have been virtually eliminated from vast areas, and the accumulation of DDT in man himself is only too well known.

D Most serious of the marsh enemies is man himself. In his quest for "lebensraum" near the water, he has all but killed the water he strives to approach. Thus up to twenty percent of the marsh--estuarine area in various parts of the country has already been utterly destroyed by cut and fill real estate developments (Figures 10, 11).

E Swimming birds such as ducks, loons, cormorants, pelicans, and many others are severely jeopardized by floating pollutants such as oil.

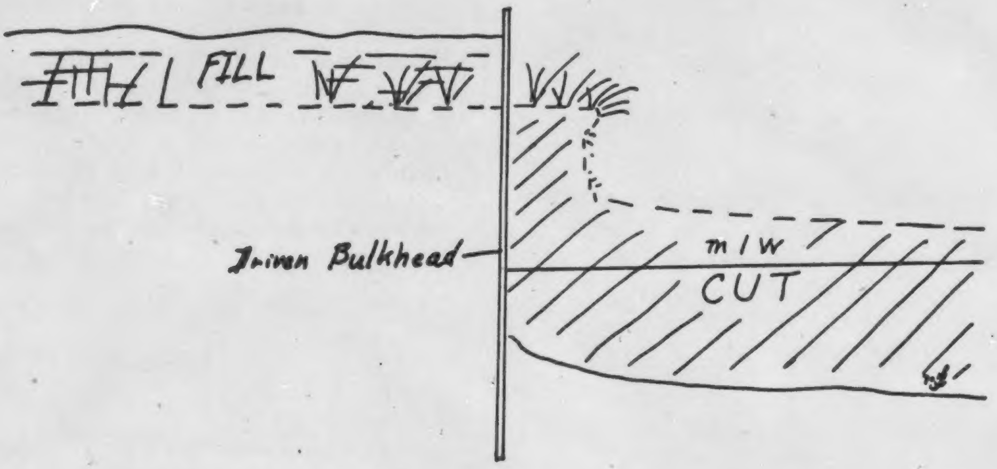
FILL
Driven Bulkhead
mlw
CUT

Figure 10. Diagrammatic representation of cut-and-fill for real estate development. mlw = mean low water

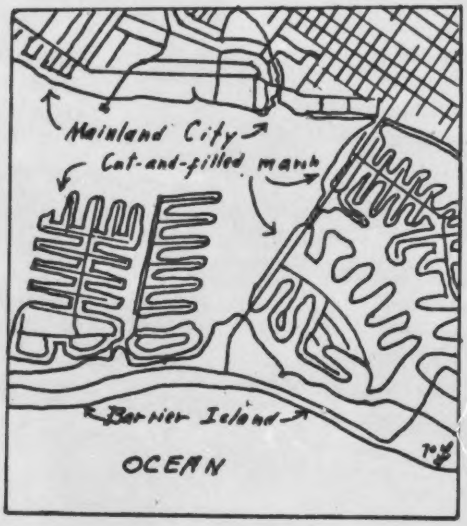
Mainland City
Cut-and-filled marsh
Barrier Island
OCEAN

Figure 11. Tracing of portion of map of a southern city showing extent of cut-and-fill real estate development.

VII SUMMARY

A Wetlands comprise the marshes, swamps, bogs, and tundra areas of the world. They are essential to the well-being of our surface waters and ground waters. They are essential to aquatic life of all types living in the open waters. They are essential as habitat for all forms of wildlife.

B The tidal marsh is the area of emergent vegetation bordering the ocean or an estuary.

C Marshes are highly productive areas, essential to the maintenance of a well rounded community of aquatic life.

D Wetlands may be destroyed by:

1 Degradation of the life forms of which it is composed in the name of nuisance control.

2 Physical destruction by cut-and-fill to create more land area.

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This outline was prepared by H. W. Jackson, former Chief Biologist, National Training Center, and revised by R. M. Sinclair, Aquatic Biologist, National Training Center, MOTD, OWPO, EPA, Cincinnati, OH 45268.

Descriptors: Aquatic Environment, Biological Estuarine Environment, Lentic Environment, Lotic Environment, Currents, Marshes, Limnology, Magnification, Water Properties

THE LAWS OF ECOLOGY

I These so-called Laws of Ecology have been collected and reformulated by Dr. Pierre Dansereau.

A They have a broad range of application in aquatic as well as terrestrial ecosystems.

B Only the ones which have strict application to fresh water organisms will be discussed.

II The Laws Verbatim

A Physiology of Ectopic Fitness (1-9)

1 Law of the inoptimum. No species encounters in any given habitat the optimum conditions for all of its functions.

2 Law of aphasy. "Organic evolution is slower than environmental change on the average, and hence migration occurs."

3 Law of tolerance. A species is confined, ecologically and geographically, by the extremes of environmental adversities that it can withstand.

4 Law of valence. In each part of its area, a given species shows a greater or lesser amplitude in ranging through various habitats (or communities); this is conditioned by its requirements and tolerances being satisfied or nearly overcome.

5 Law of competition-cooperation. Organisms of one or more species occupying the same site over a given period of time, use (and frequently reuse) the same resources through various sharing processes which allow a greater portion to the most efficient.

6 Law of the continuum. The gamut of ecological niches, in a regional unit, permits a gradual shift in the qualitative and quantitative composition and structure of communities.

7 Law of cornering. The environmental gradients upon which species and communities are ordained either steepen or smoothen at various times and places, thereby reducing utterly or broadening greatly that part of the ecological spectrum which offers the best opportunity to organisms of adequate valence.

8 Law of persistence. Many species, especially dominants of a community, are capable of surviving and maintaining their spatial position after their habitat and even the climate itself have ceased to favor full vitality.

9 Law of evolutionary opportunity. The present ecological success of a species is compounded of its geographical and ecological breadth, its population structure, and the nature of its harboring communities.

B Strategy of Community Adjustment (10-14)

10 Law of ecesis. The resources of an unoccupied environment will first be exploited by organisms with high tolerance and generally with low requirements.

11 Law of succession. The same site will not be indefinitely held by the same plant community, because the physiographic agents and the plants themselves induce changes in the whole environment, and these allow other plants heretofore unable to invade, but now more efficient, to displace the present occupants.

12 Law of regional climax. The processes of succession go through a shift of controls but are not indefinite, for they tend to an equilibrium that allows no further relay; the climatic-topographic-edaphic-biological balance of forces results in an ultimate pattern which shifts from region to region.

13 Law of factorial control. Although living beings react holocenotically (to all factors of the environment in their peculiar conjunction), there frequently occurs a discrepant factor which has controlling power through its excess or deficiency.

14 Law of association segregation. Association of reduced composition and simplified structure have arisen during physiographic or climatic change and migration through the elimination of some species and the loss of ecological status of others.

C Regional Climatic Response (15-20)

15 Law of geoecological distribution. "The specific topographical distribution (microdistribution) of an ecotypic plant species or of a plant community is a parallel function of its general geograpical distribution (macrodistribution), since both are determined by the same ecological amplitudes and ultimately by uniform physiological requirements."

16 Law of climatic stress. It is at the level of exchange between the organism and the environment (microbiosphere) that the stress is felt which eventually cannot be overcome and which will establish a geographic boundary.

17 Law of biological spectra. Life-form distribution is a characteristic of regional floras which can be correlated to climatic conditions of the present as well as of the past.

18 Law of vegetation regime. Under a similar climate, in different parts of the world, a similar structural-physiognomic-functional response can be induced in the vegetation, irrespective of floristic affinities and/or historical connections.

19 Law of zonal equivalence. Where climatic gradients are essentially similar, the latitudinal and altitudinal zonation and cliseral shifts of plant formations also tend to be; where floristic history is essentially identical, plant communities will also be similar.

20 Law of irreversibility. Some resources (mineral, plant, or animal) do not renew themselves, because they are the result of a process (physical or bilogical) which has ceased to function in a particular habitat of landscape at the present time.

21 Law of specific integrity. Since the lower taxa (species and subordinate units) cannot be polyphyletic, their presence in widely separated areas can be explained only by former continuity or by migration.

22 Law of phylogenetic trends. The relative geographical positions, within species (but more often genera and families), of primitive and advanced phylogenetic features are good indicators of the trends of migration.

23 Law of migration. Geographical migration is determined by population pressure and/or environmental change.

24 Law of differential evolution. Geographic and ecological barriers favor independent evolution, but the divergence of vicariant pairs is not necessarily proportionate to the gravity of the barrier or the duration of isolation.

25 Law of availability. The geographic distribution of plants and animals is limited in the first instance by their place and time of origin.

26 Law of geological alternation. Since the short revolutionary periods have a strong selective force upon the biota, highly differentiated life forms are are more likely to develop during those times than during equable normal periods.

27 Law of domestication. Plants and animals whosw selection has been more or less dominated by man are rarely able to survive without his continued protection.

III THIENEMANN'S ECOLOGICAL PRINCIPLES

These three principles apply to stream invertebrates and will be noted specifically during your stream examinations as you compare aquatic communities.

A The greater the diversity of the conditions in a locality the larger is the number of species which make up the biotic community.

B The more the conditions in a locality deviate from normal, and hence from the normal optima of most species, the smaller is the number of species which occur there and the greater the number of individuals of each of the species which do occur.

C The longer a locality has been in the same condition the richer is its biotic community and the more stable it is.

IV THE LAW OF THE EQUIVALENCE OF WINDOWS (deAssis)

"The way to compensate for a closed window is to open another window."

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This outline was prepared by Ralph M. Sinclair, Aquatic Biologist, National Training Center, MP&OD, WPO, USEPA, Cincinnati, OH 45268.

Descriptor: Ecology.

AQUATIC ORGANISMS OF SIGNIFICANCE IN POLLUTION SURVEYS

I INTRODUCTION

A Any organism encountered in a survey is of significance. Our problem is thus not to determine which are of significance but rather to decide "what is the significance of each?"

B The first step in interpretation is recognition. "The first exercise in ecology is systematics."

C Recognition implies identification and an understanding of general relationships (systematics). The following outline will thus review the general relationships of living (as contrasted to fossil) organisms and briefly describe the various types.

D The species problem

1 Necessity of identifying species

Studies of the ecology of any habitat require the identification of the organisms found in it. One cannot come up with definitive evaluations of stress on the biota of a system unless we can say what species constitute the biota. Species vary in their responses to the impact of the environment.

2 Solutions to the problem

a Evasion

Treat the ecosystem as a "black box"--a unit--while ignoring the constitution of the system. This may produce some broad generalizations and will certainly yield more questions than answers.

b Compromise

Work only with those taxonomic categories with which one has the competence to deal. Describe the biotic component as a taxocenosis limited to one or two numerically dominant taxonomic categories, bearing in mind that numerically taxa which are ignored may be very important to the ecology of the ecosystem.

c Comprehensive description

Attempt a comprehensive description of the biota. No one can claim competence to deal with more than one or two groups. The cooperation of experts must be obtained. The Smithsonian Institution has a clearinghouse for this sort of thing.[1] Lists of expert taxonomists can be obtained. There will be none for some groups. Also collaboration is time consuming.

3 Fungi: extracellular digestion (enzymes secreted externally.) Food material then taken in through cell membrane where it is metabolized and reduced to the mineral condition. Ecologically known as REDUCERS.

E Each of these groups includes simple, single-celled representatives, persisting at lower levels on the evolutionary stems of the higher organisms.

1 These groups span the gaps between the higher kingdoms with a multitude of transitional forms. They are collectively called the PROTISTA.

2 Within the protista, two principal sub-groups can be defined on the basis of relative complexity of structure.

a The bacteria and blue-green algae, lacking a nuclear membrane may be considered as the lower protista (or Monera).

b The single-celled algae and protozoa are best referred to as the higher protista.

F Distributed throughout these groups will be found most of the traditional "phyla" of classic biology.

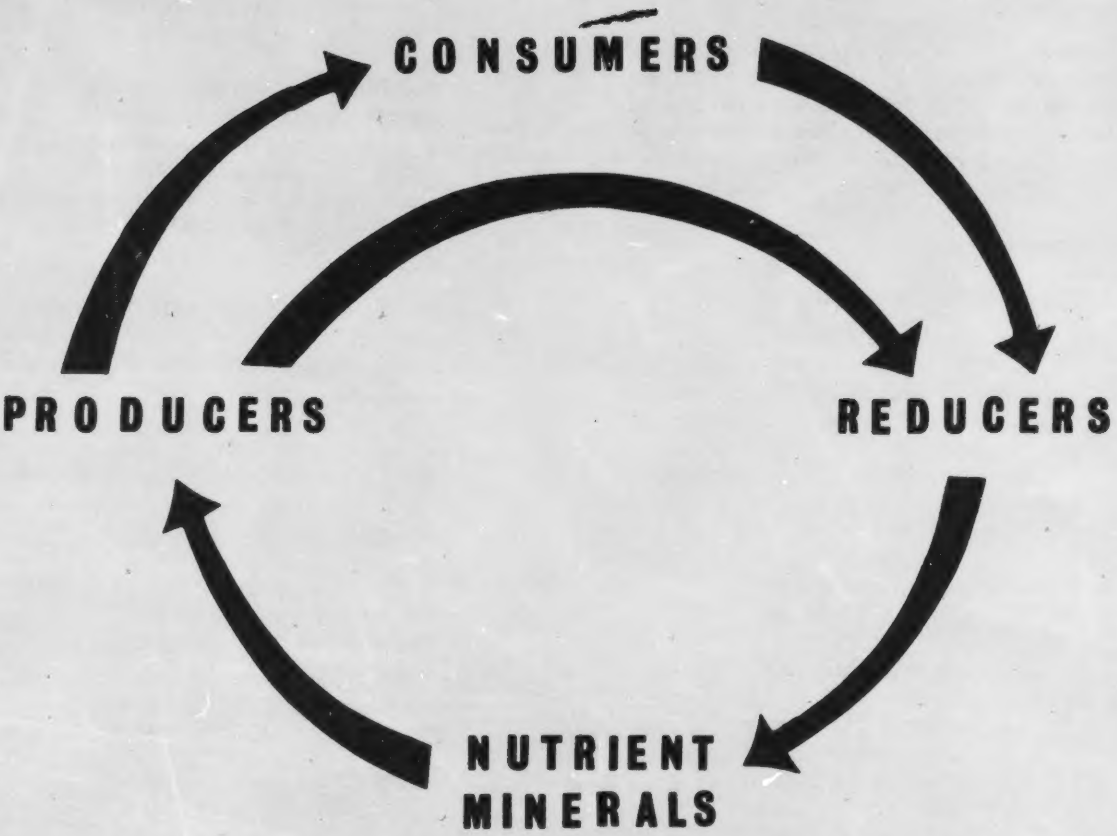

CONSUMERS
PRODUCERS
REDUCERS
NUTRIENT MINERALS

Figure 1. BASIC CYCLES OF LIFE

II PLANTS

A The vascular plants are usually larger and possess roots, stems, and leaves.

1 Some types emerge above the surface (emersed).

2 Submersed typed typically do not extend to the surface.

3 Floating types may be rooted or free-floating.

B Algae generally smaller, more delicate, less complex in structure, possess chlorophyll like other green plants. For convenience the following artificial grouping is used in sanitary science:

1 "Blue-green algae" are typically small and lack an organized nucleus, pigments are dissolved in cell sap. Structure very simple.

2 "Pigmented flagellates" possess nuclei, chloroplasts, flagellae and a red eye spot. This is an artificial group containing several remotely related organisms, may be green, red, brown, etc.

3 "Diatoms" have "pillbox" structure of SiO_2 - may move. Extremely common. Many minute in size, but colonial forms may produce hair-like filaments. Golden brown in color.

4 "Non-motile green algae" have no locomotor structure or ability in mature condition. Another artificial group.

a Unicellular representatives may be extremely small.

b Multicellular forms may produce great floating mats of material.

III FUNGI

Lack chlorophyll and consequently most are dependent on other organisms. They secrete extracellular enzymes and reduce complex organic material to simple compounds which they can absorb directly through the cell wall.

A Schizomycetes or bacteria are typically very small and do not have an organized nucleus.

1 Autotrophic bacteria utilize basic food materials from inorganic substrates. They may be photo-synthetic or chemosynthetic.

2 Heterotrophic bacteria are most common. The require organic material on which to feed.

B "True fungi" usually exhibit hyphae as the basis of structure.

IV ANIMALS

A Lack chlorophyll and consequently feed on or consume other organisms. Typically ingest and digest their food.

B The Animal Phyla

1 PROTOZOA are single celled organisms; many resembling algae but lacking chlorophyll (cf: illustration in "Oxygen" lecture).

2 PORIFERA are the sponges; both marine and freshwater representatives.

3 CNIDARIA (= COELENTERATA) include corals, marine and freshwater jelly fishes, marine and freshwater hydroids.

4 PLATYHELMINTHES are the flat worms such as tape worms, flukes and Planeria.

5 NEMATHELMINTHES are the round worms and include both free-living forms and many dangerous parasites.

6 ROTIFERS are multicellular microscopic predators.

7 BRYOZOA are small colonial sessile forms, marine or freshwater.

8 MOLLUSCA include snails and slugs, clams, mussels and oysters, squids, and octopi.

9 BRACHIOPODS are bivalved marine organisms usually observed as fossils.

10 ANNELIDS are the segmented worms such as earthworms, sludge worms and many marine species.

11 ECHINODERMS include starfish, sea urchins and brittle stars. They are exclusively marine.

12 CTENOPHORES, or comb jellies, are delicate jelly-like marine organisms.

13 ARTHROPODA, the largest of all animal phyla. They have jointed appendages and a chitinous exoskelton.

a CRUSTACEA are divided into a cephalothoraz and abdomen, and have many pairs of appendages, including paired antennae.

1) CLADOCERA include Daphina a common freshwater microcrustacean; swim by means of branched antennae.

2) ANOSTRACA (=PHYLLOPODS) are the fairy shrimps, given to eruptive appearances in temporary pools.

3) COPEPODES are marine and freshwater microcrustacea--swim by means of unbranced antennae.

4) OSTRACODS are like microscopic "clams with legs."

5) ISOPODS are dorsoventrally compressed; called sowbugs. Terrestrial and aquatic, marine and freshwater.

6) AMPHIPODA - known as scuds, laterally compressed. Marine and freshwater.

7) DECAPODA - crabs, shrimp, crayfish, lobsters, etc. Marine and freshwater.

b INSECTA - body divided into head, thorax and abdomen; 3 paris of legs; adults typically with 2 pairs of wings and one pair of antennae. No common marine species. Nine of the twenty-odd orders include species with freshwater-inhabiting stages in their life history as follows:

1) DIPTERA - two-winged flies

2) COLEOPTERA - beetles

3) EPHEMEROPTERA - may flies

4) TRICHOPTERA - caddis flies

5) PLECOPTERA - stone flies

6) ODONATA - dragon flies and damsel flies

7) NEUROPTERA - alder flies, Dobson flies and fish flies.

8) HEMIPTERA - true bugs, sucking insects such as water striders, electric light bugs and water boatman

9) LEPIDOPTERA - butterflies and moths, includes a few freshwater moths

c ARACHINIDA - body divided into cephalothorax and abdomen; 4 pairs of legs - spiders, scorpions, ticks and mites. Few aquatic representatives except for the freshwater mites and tardigrades.

C CHORDATA

1 PROTOCHORDATES - primitive marine forms such as acorn worms, sea squirts and lancelets

2 VERTEBRATES - all animals which have a backbone

a PICES or fishes: including such forms as sharks and rays, lampreys, and higher fishes; both marine and freshwater b AMPHIBIA - frogs, toads, and salamanders - marine species rare.

c REPTILA - snakes, lizards and turtles.

d MAMMALS - whales and other warm-blooded vertebrates with hair.

e AVES - birds - warm-blooded vertebrates with feathers.

REFERENCE

Whittaker, R. H. New Concepts of Kingdoms of Organisms. Science 163:150-160. 1969.

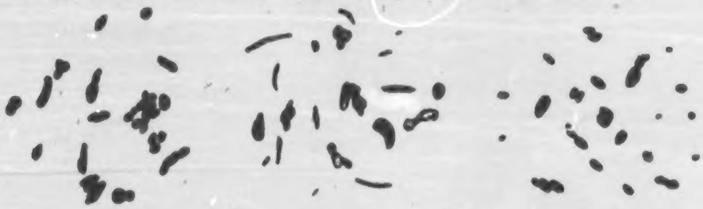
This outline was prepared by H. W. Jackson, formerly Chief Biologist, National Training Center, and revised by R. M. Sinclair, Aquatic Biologist, National Training Center, MPOD, OWPO, EPA, Cincinnati, OH 45268.

Descriptors:
Aquatic Life; Systematics, Streams, Surveys, Stream Pollution

FUNGI

3/4

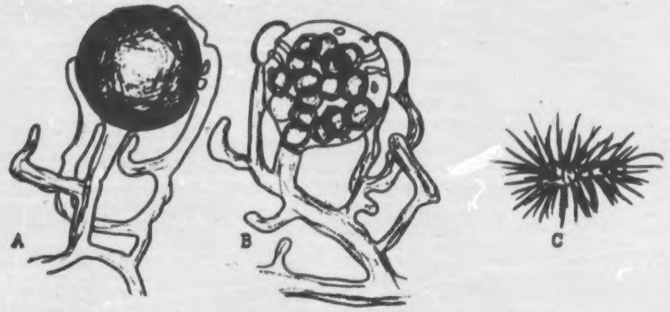
Schizomycetes - Bacteria, free living representatives



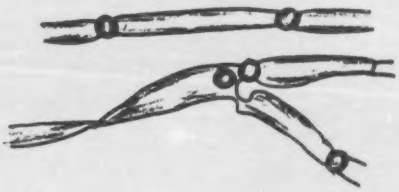
Aerobacter aerogenes

Rhizobium radicicola

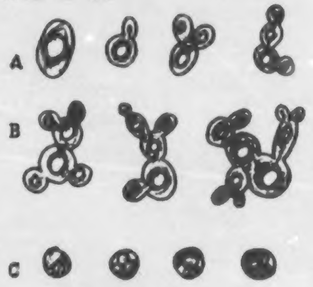
Azotobacter



Phycomycetes - Saprolegnia; A, detail of immature reproductive stages; B, mature oogonium and antheridia, with eggs and fertilization tubes; C, dead tadpole with growth of S.



Phycomycete - Leptomitus, this genus includes pollution tollerant species.



Ascomycete - Saccharomyces, a yeast including poll. tollerant species. A, single cell; B, budding; C, ascospore formation.

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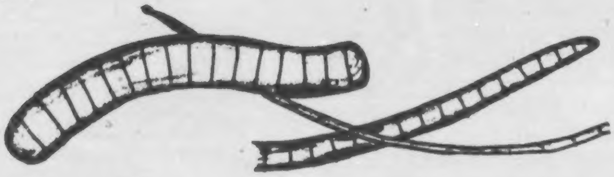
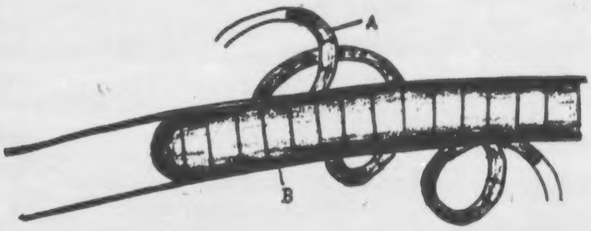
PLATE I

BLUE GREEN ALGAE

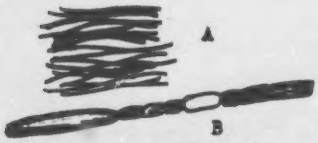
3/4



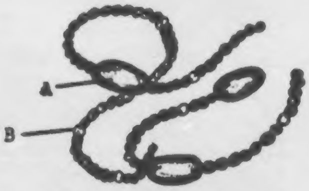
Oscillatoria spp., filaments (trichomes) range from .6 to over 60µ in diameter. Ubiquitous, pollution tollerant.



Lyngbia spp., similar to *Oscillatoria* but has a sheath.
A, *Lyngbia contorta*, reported to be generally intollerant of pollution; B, L. birgei.



Aphanizomenon flos-aquae
A, colony; B, filament



Anabaena flos-aquae
A, akinete; B, heterocyst

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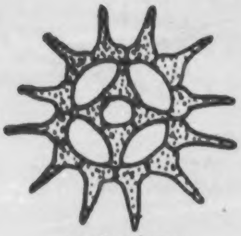
PLATE II

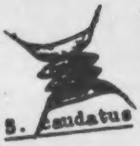
1/67

NON-MOTILE GREEN ALGAE: COCCOID
(CHLOROPHYCEAE)

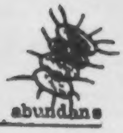


Pediastrum

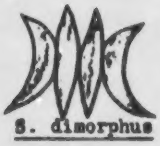
Species of the Genus Scenedesmus



S. caudatus

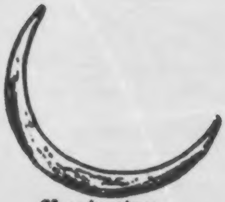


S. abundans

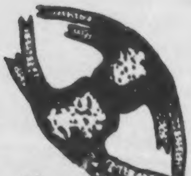


S. dimorphus

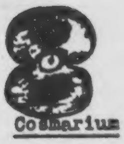
Desmids



Closterium



Staurastrum



Cosmarium

PLATE III

11/3 NON-MOTILE GREEN ALGAE: FILAMENTOUS

(Chlorophyceae)

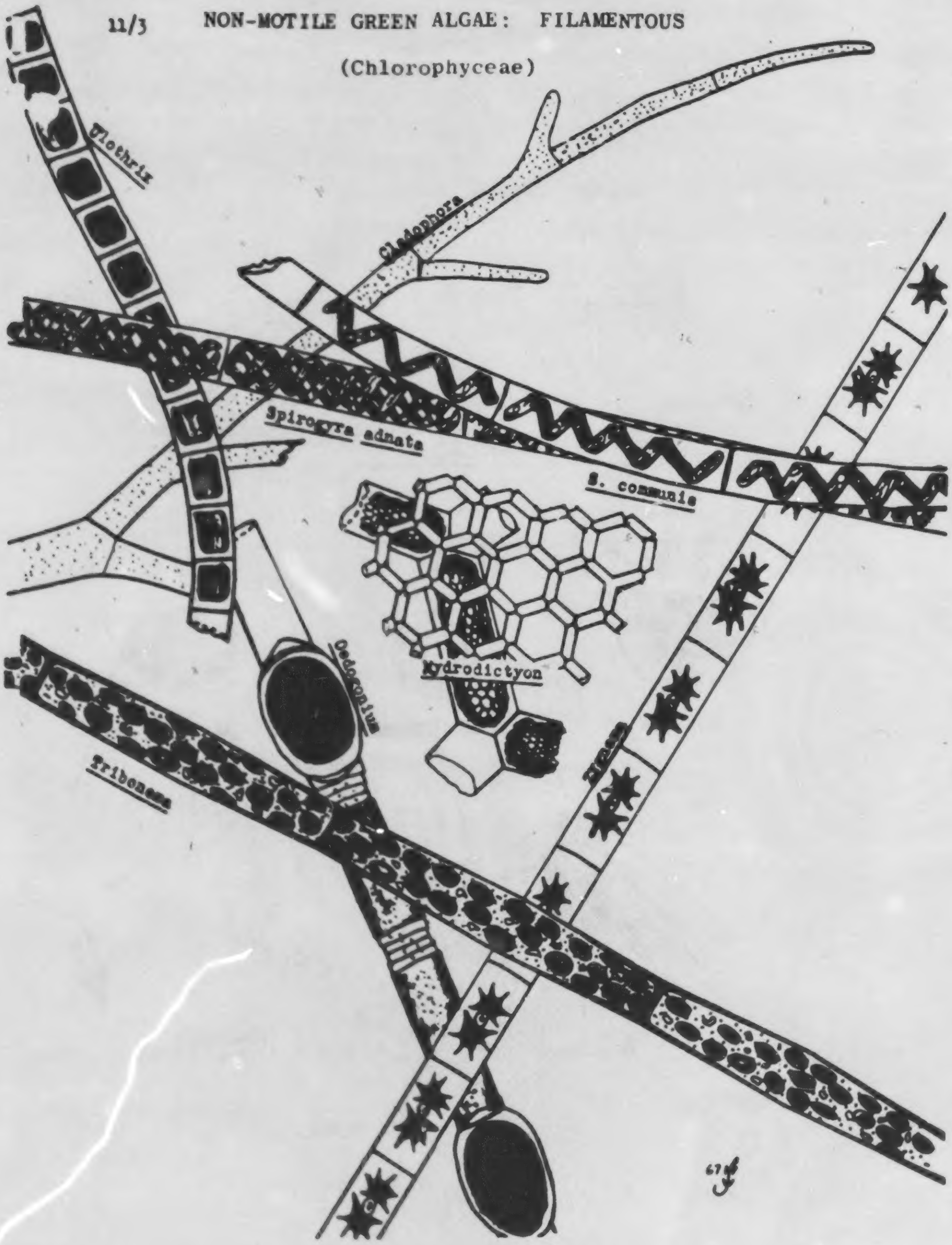
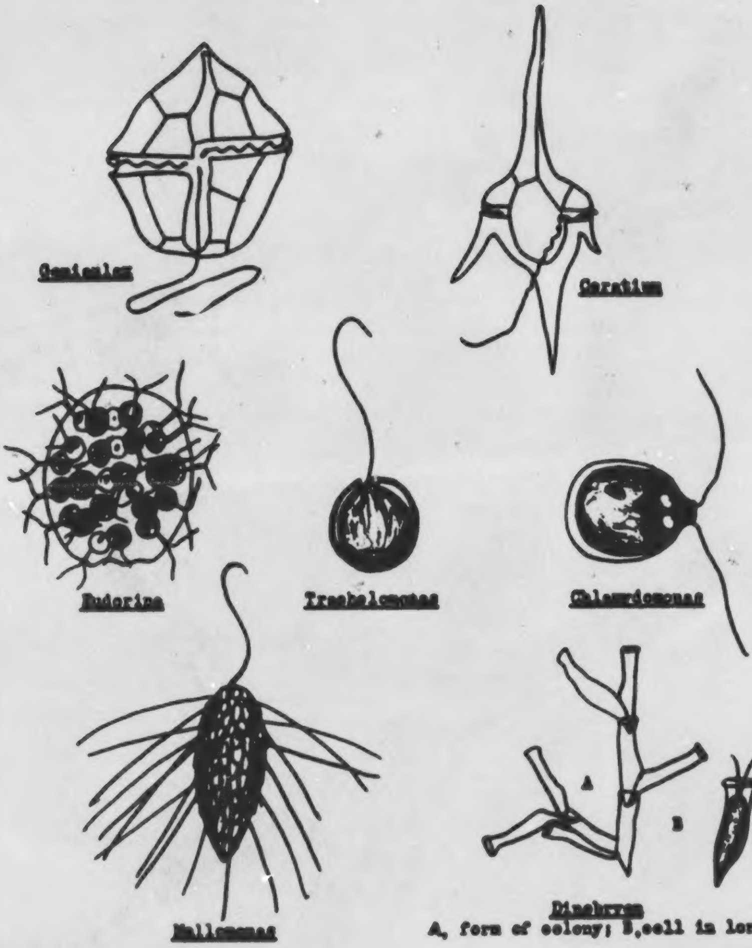

Ulothrix
Cladophora
Spirogyra adnata
S. communis
Hydrodictyon
Oedogonium
Tribonema
Zygnema

PLATE IV

PIGMENTED FLAGELLATES

3/4


Gonyaulax
Ceratium
Eudorina
Trachelomonas
Chlamydomonas
Mallomonas
A
B
Dinobryon

A, form of colony; B,cell in lorica.

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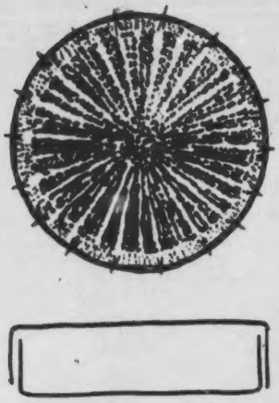
PLATE V

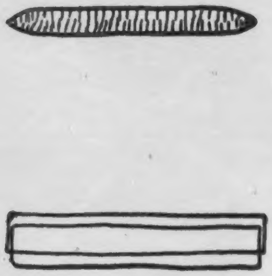
DIATOMS

3/4



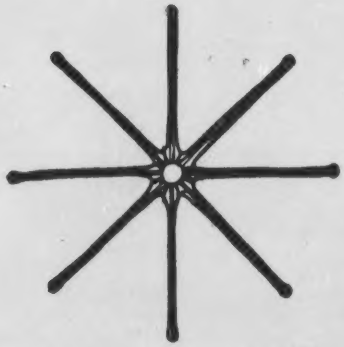
Valve views

Girdle views, stylized to show basic diatom structure.

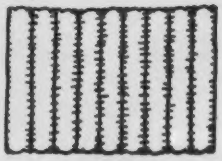


A discoid or central diatom such as *Stephanodiscus*

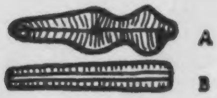
A pennate or navicular diatom such as *Fragillaria*



A colony of *Asterionella* (girdle views)



A colony of *Fragillaria* (girdle views)



Gomphonema
A, valve view; B, girdle view.

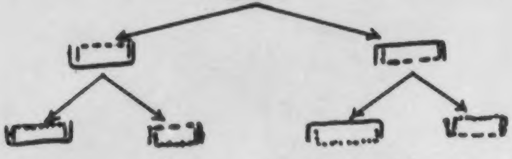


Diagram showing progressive diminution in the size of certain frustules through successive cell generations of a diatom.

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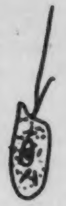
PLATE VI

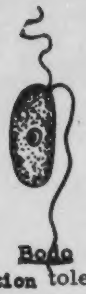
3/4

FREE LIVING PROTOZOA

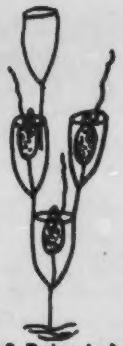
I. Flagellated Protozoa, Class Mastigophora



Anthophysis
Pollution tolerant
6 µ

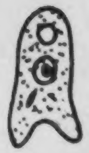


Bodo
Pollution tolerant
19 µ

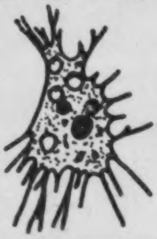


Colony of **Poteriodendron**
Pollution tolerant , 35 µ

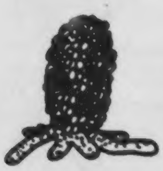
II. Ameboid Protozoa, Class Sarcodina



Dimastigamoeba
Pollution tolerant
10-50 µ

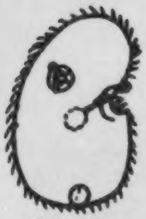


Nuclearia, reported
to be intolerant of
pollution, 45 µ.

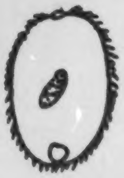


Difflugia
Pollution tolerant
60-500 µ

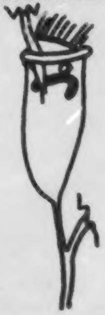
III. Ciliated Protozoa, Class Ciliophora



Colpoda
Pollution tolerant
20-120 µ



Holophrya, reported
to be intolerant of
pollution, 35 µ

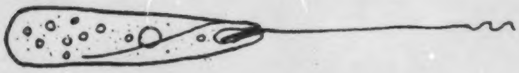


Epistylis, pollution
tolerant Colonies often
macroscopic.

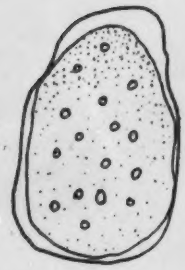
PLATE VII

H.W.Jackson

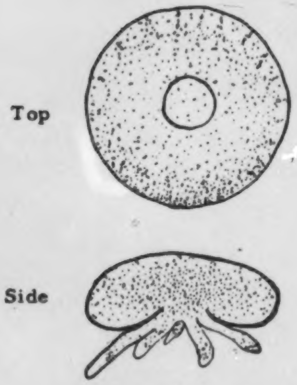
PLANKTONIC PROTOZOA



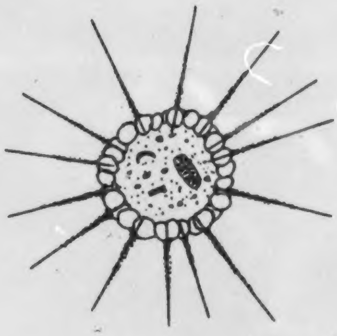
Peranema trichophorum



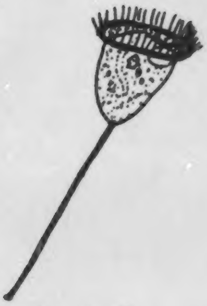
Chaos



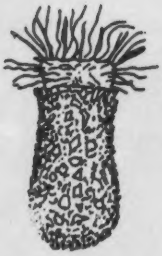
Arcella vulgaris



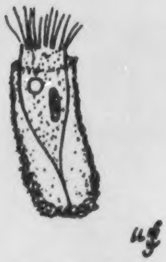
Actinosphaerium



Vorticella



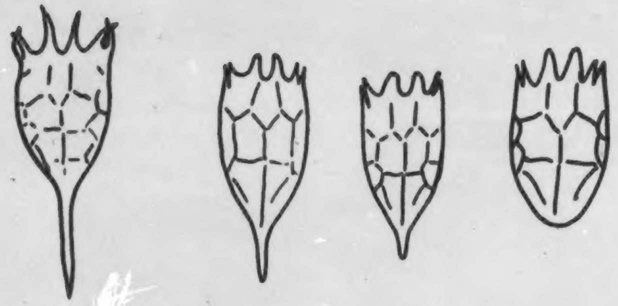
Codonella cratera



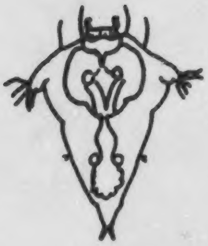
Tintinnidium fluviatle

PLATE VIII

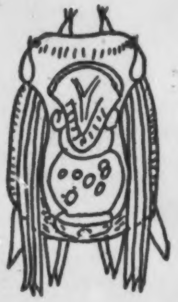
PLANKTONIC ROTIFERS



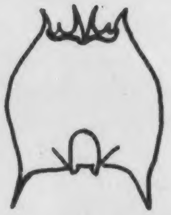
Various Forms of Keratella cochlearis



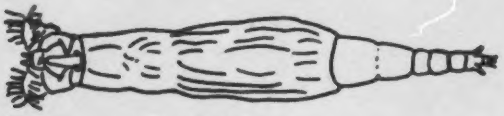
Synchaeta pectinata



Polygarthra vulgaris



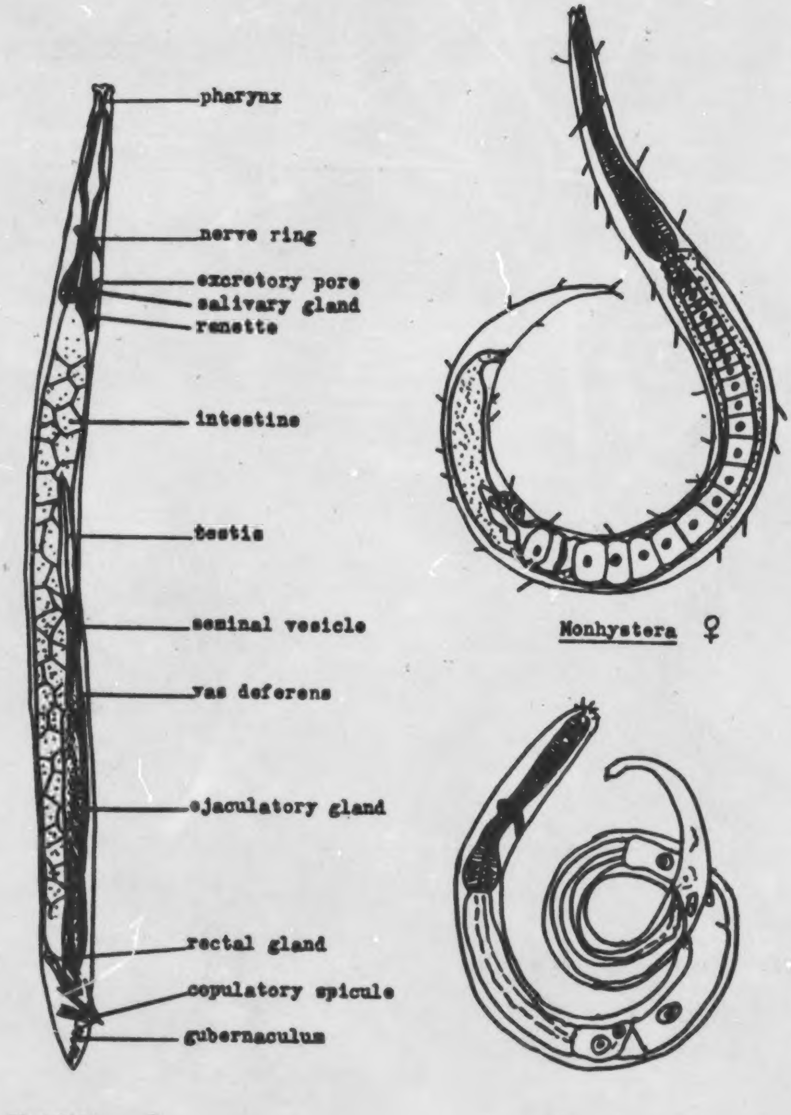
Brachionus quadridentata



Rotaria sp

PLATE IX

FREE LIVING NEMATHELMINTHES, OR ROUND WORMS


pharynx
nerve ring
excretory pore
salivary gland
renette
intestine
testis
seminal vesicle
vas deferens
ejaculatory gland
rectal gland
copulatory spicule
gubernaculum

Rhabditis ♂

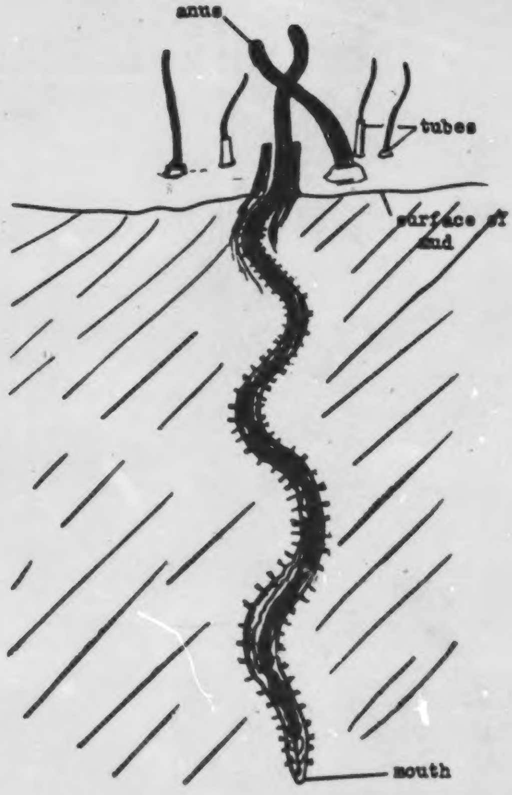
Monhystera ♀

Achromadora ♀

PLATE X

FRESH WATER ANNELID WORMS

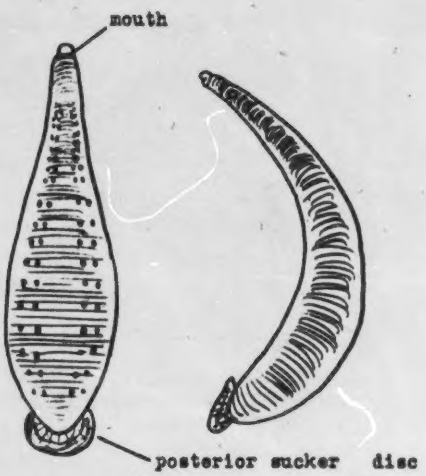
Phylum Annelida


anus
tubes
surface of mud
mouth

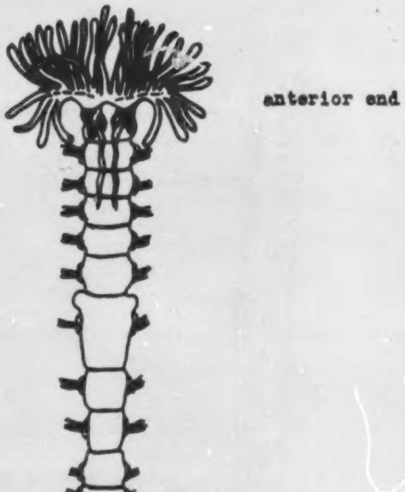
Class Oligochaeta, earthworms

Ex: Tubifex , the sludgeworm

(After Liebman)


mouth
posterior sucker disc

Class Hirudinea, leeches
(After Hegner)


anterior end

Class Polychaeta , polychaet worms

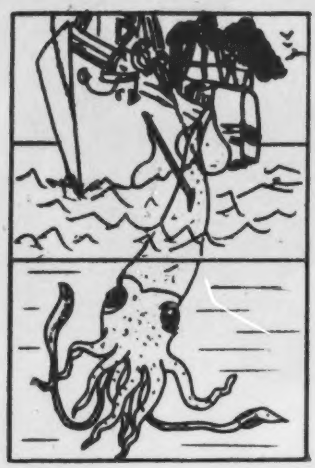
Ex: Manayunkia, a minute, rare, tube building worm.
(After Leidy)

H.W.Jackson

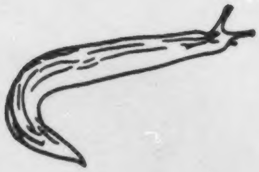
PLATE XI

SOME MOLLUSCAN TYPES

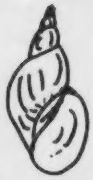
Class; Cephalopoda; Squids, octopus, cuttlefish.



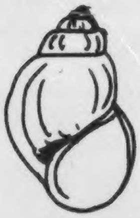
Exclusively marine. The giant squid shown was captured in the Atlantic in the early ninteenth century. (After Hegner)



Limax, a slug

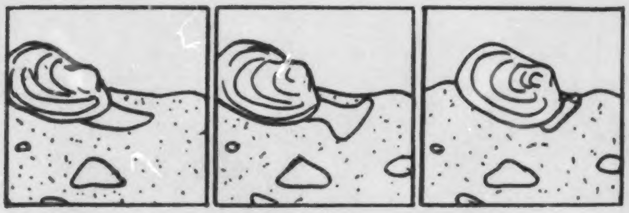


Lymnaea an air breathing snail



Campeloma a water breathing snail

Class; Gastropoda; snails and slugs. (After Buchsbaum)



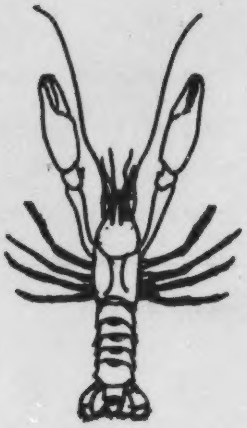
Class; Pelecypoda; clams, mussels, oysters.

Locomotion of a freshwater clam, showing how foot is extended, the tip expanded, and the animal pulled along to its own anchor. (After Buchsbaum)
H.W.Jackson

PLATE XII

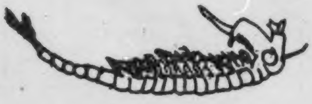
Class CRUSTACEA

3/4



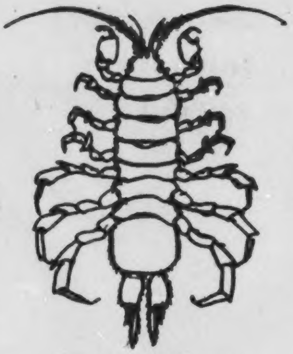
Crayfish, or crawdad; *Cambarus*, Order Decapoda

10-20 cm



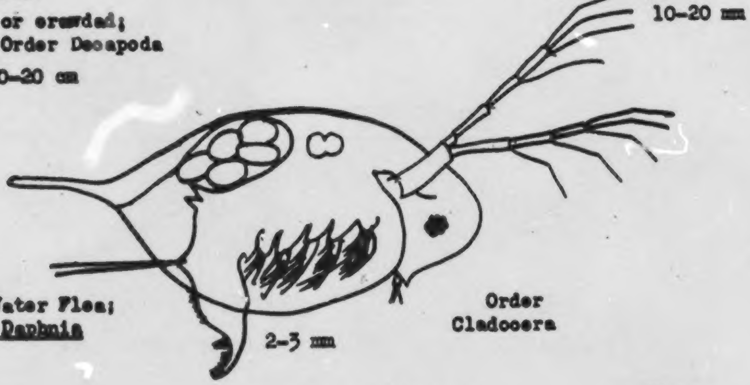
Fairy Shrimp; *Eubranchipus*, Order Phyllopoda

20-25 mm



Sow Bug; *Asellus*, Order Isopoda

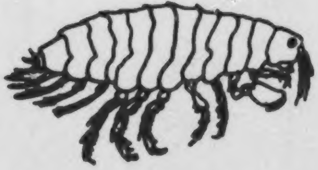
10-20 mm



Water Flea; *Daphnia*

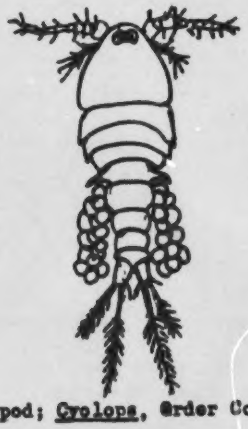
2-3 mm

Order Cladocera



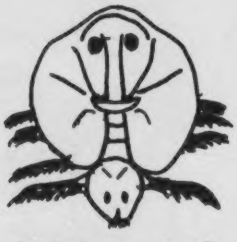
Scud; *Hyalella* Order Amphipoda

10-15 mm



Copepod; *Cyclops*, Order Copepoda

2-3 mm



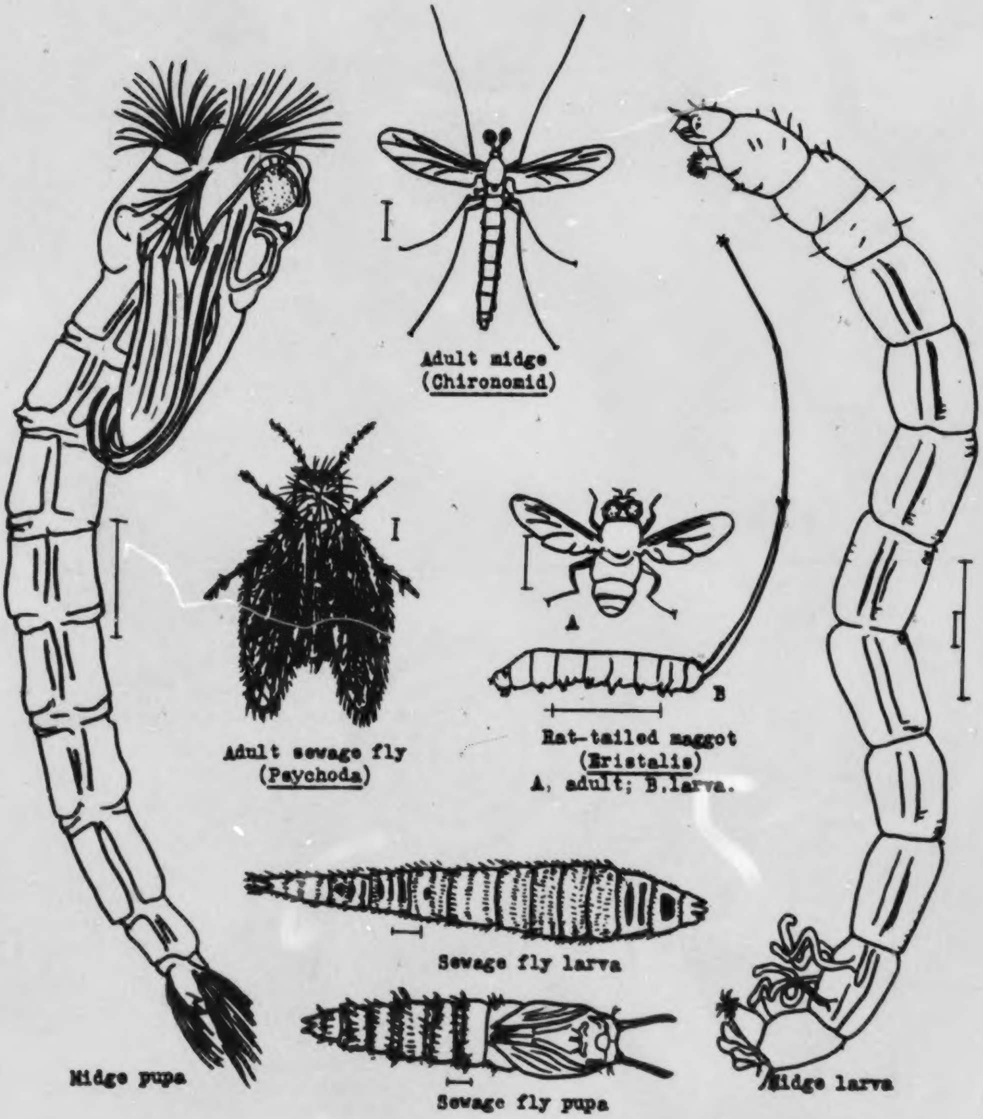
Fish Louse, *Argulus*; a parasitic Copepod

5-6 mm

H.W.Jackson

PLATE XIII

Two Winged Flies
Order DIPTERA



Adult midge
(Chironomid)

Adult sewage fly
(Psychoda)

Rat-tailed maggot
(Eristalis)
A, adult; B, larva.

Sewage fly larva

Sewage fly pupa

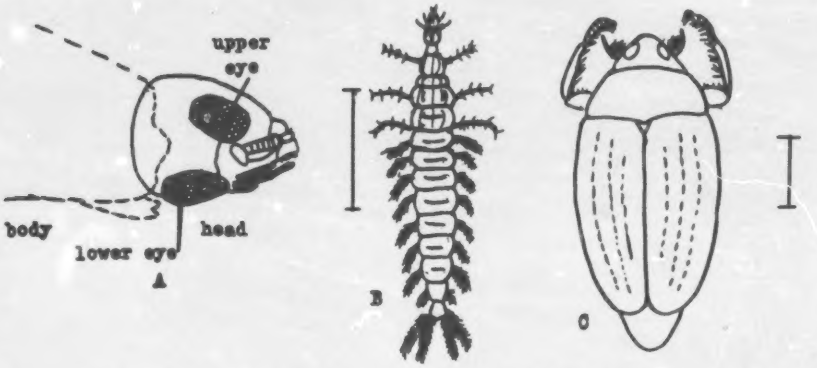
Midge pupa

Midge larva

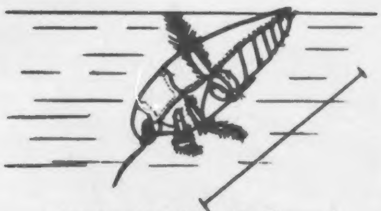
H.W.Jackson
After various authors

PLATE XIV

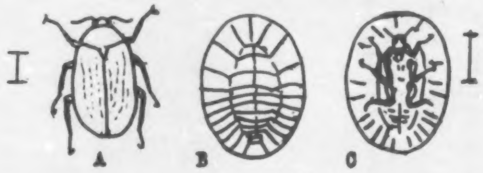
Beetles
Order COLEOPTERA



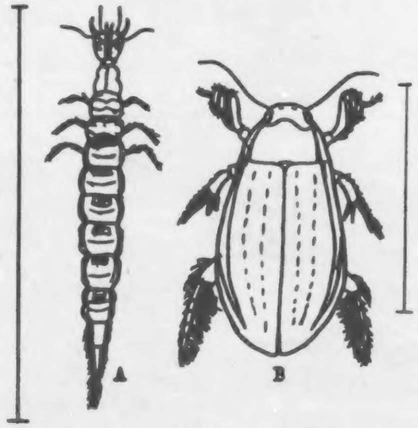
Whirligig beetle (Gyrinus) A, Side view of head of adult showing divided eye; B, Larva; C, Adult. Carnivorous.



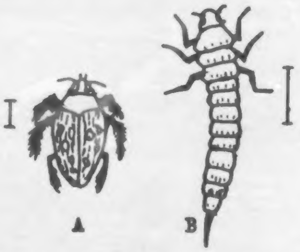
A diving beetle (Dytiscus) taking air at the surface.



The riffle beetle (Psephenus); A, adult; B, dorsal side of larva; C, ventral side of larva. Predominantly herbivorous.



A diving beetle (Cybister). The diving beetles include some of the largest and most voracious of aquatic insects. A, larva; B, adult.



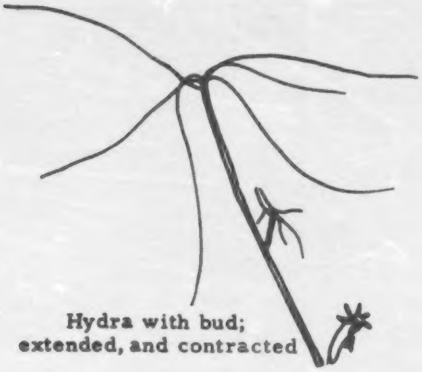
Crawling water beetle; A; adult; B, larva. Predominantly herbivorous.

H.W.Jackson. After Needham, Pennak, Morgan, and others.

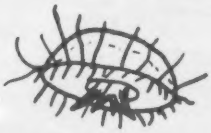
PLATE XV

MINOR PHYLA

Phylum Coelenterata

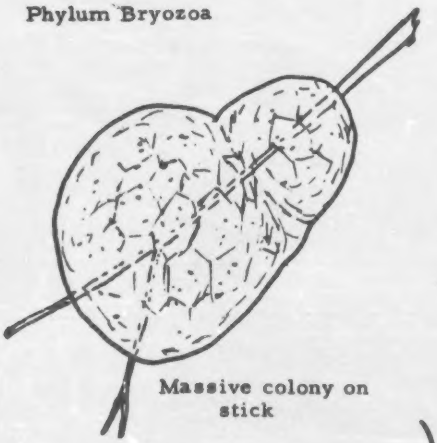


Hydra with bud; extended, and contracted

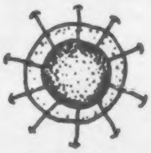


Medusa of *Craspedacusta*

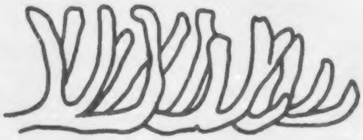
Phylum Bryozoa



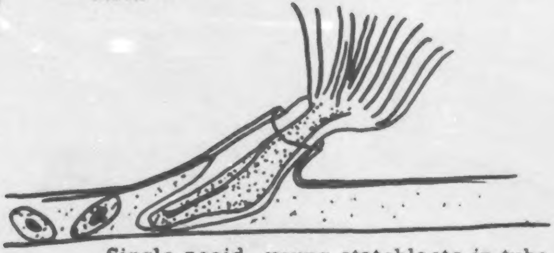
Massive colony on stick



Statoblast



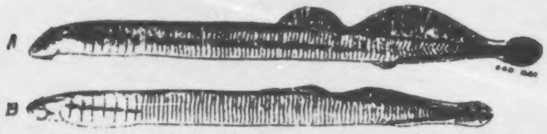
Creeping colony on rock



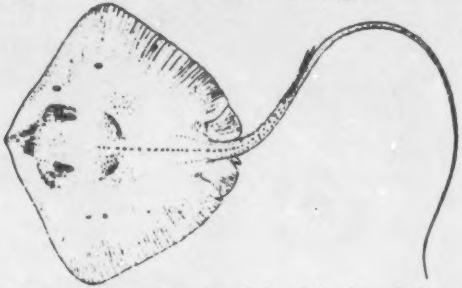
Single zooid, young statoblasts in tube

PLATE XVI

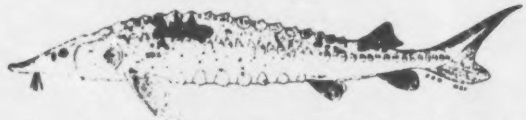
SOME PRIMITIVE FISHES



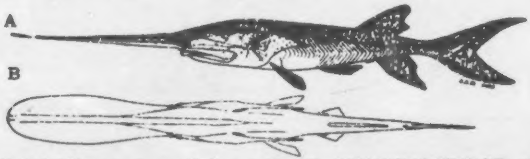
Class Agnatha, jawless fishes (lampreys and hagfishes) - Family PETROMYZONTIDAE, the lampreys. Lampetra aepyptera, the Brook Lamprey A: adult, B: larva (enlarged)



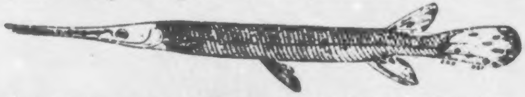
Class Chondrichthyes - cartilagenous fishes (sharks, skates, rays) Family DASYATIDAE - stingrays. Dasyatis centroura, the Roughtail Stingray



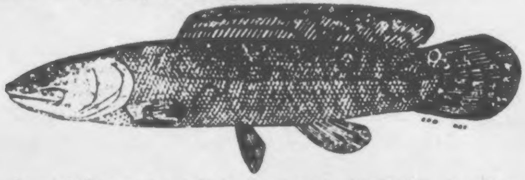
Class Osteichthyes - bony fishes - Family ACIPENSERIDAE, sturgeon. Acipenser fulvescens, the Lake Sturgeon



Class Osteichthyes - bony fishes - Family POLYODONTIDAE, the paddlefishes. Polyodon spathula, the Paddlefish. A:side view B:top view



Class Osteichthyes - bony fishes - Family LEPISOSTEIDAE - gars Lepisosteus osseus, the Longnose Gar



Class Osteichthyes - bony fishes - Family AMIIDAE, bowfins Aniia calva, the Bowfin

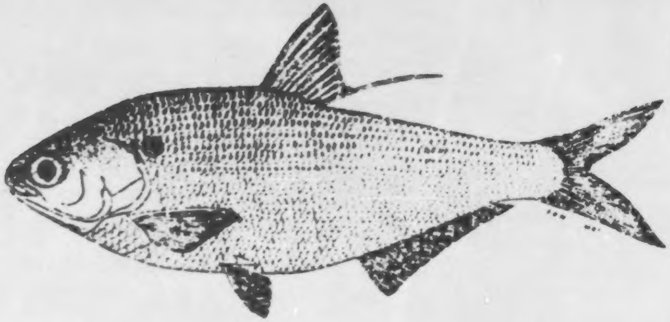
Reproduced with permission; Trautman, 1957.

BI. AQ. pl. 91. 6. 60

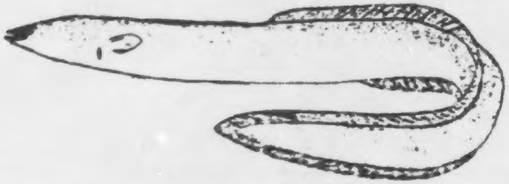
PLATE XVII

TYPES OF BONY FISHES

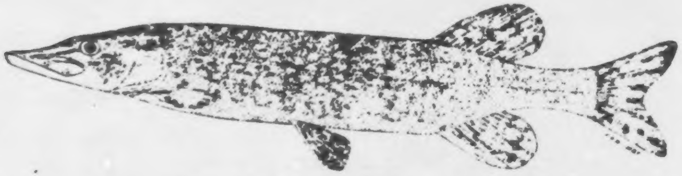
PLATE XVIII



Family CLUPEIDAE - herrings
Dorosoma cepedianum - the eastern gizzard shad



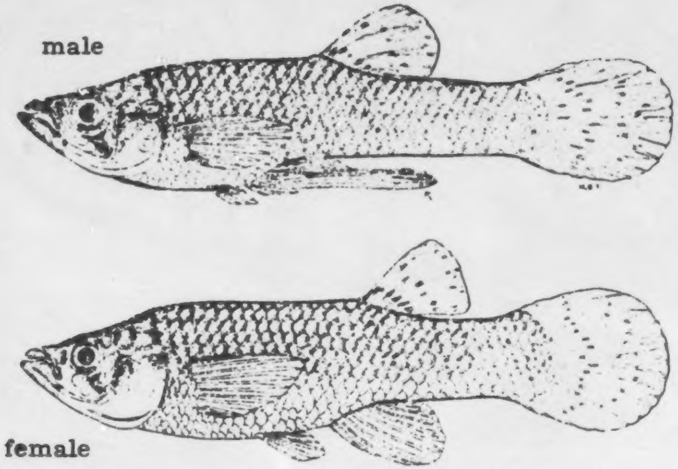
Family ANGUILLEDAE - freshwater eels
Anguilla rostrata - the American eel



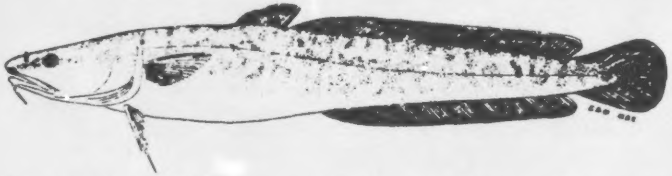
Family ESOCIDAE - pikes
Esox lucius - the northern pike

Reproduced with permission; Trautman, 1957.

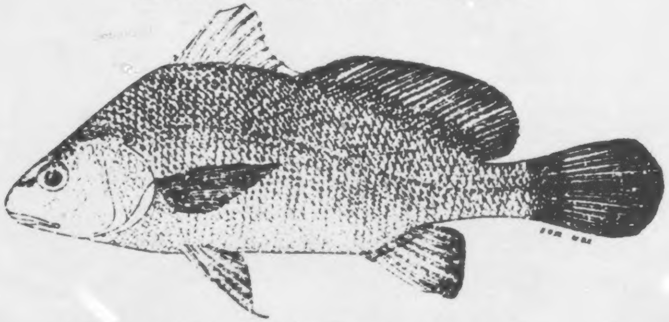
BI. AQ. pl. 9m. 6.60



Family POECILIIDAE - livebearers
Gambusia affinis - the mosquitofish



Family GADDIDAE - codfishes, hakes, haddock, burbot
Lota lota - the eastern burbot



Family SCIAENIDAE - drums
Aplodinotus grunniens - the freshwater drum

BIOLOGICAL ASPECTS OF NATURAL SELF PURIFICATION

I INTRODUCTION

A The results of natural self purification processes are readily observed. Did they not exist, sewage (and other organic wastes) would forever remain, and the world as we know it would long ago have become uninhabitable. Physical, chemical, and biological factors are involved. The microscopic and macroscopic animals and plants in a body of water receiving organic wastes are not only exposed to all of the various (ecological) conditions in that water, but they themselves create and profoundly modify certain of those conditions.

B Since toxic chemicals kill some of or all of the aquatic organisms, their presence disrupts the natural self purification processes, and hence, will not be considered here. The following discussion is based solely on the effects of organic pollution such as sewage or other readily oxidizable organic wastes.

C This description is based on the concept of a "stream" since under the circumstances of stream or river flow, the events and conditions occur in a linear succession. The same fundamental processes occur in lakes, estuaries, and oceans, except that the sequence of events may become telescoped or confused due to the reduction or variability of water movements.

D The particular biota (plants and animals, or flora and fauna) employed as illustrations below are typical of central United States. Similar or equivalent forms occur in similar circumstances in other parts of the world.

E This presentation is based on an unpublished chart produced by Dr. C.M. Tarzwell and his co-workers in 1951. Examples from this chart are employed in the presentation.

II THE STARTING POINT

A A normal unpolluted stream is assumed as a starting point. (Figure 1)

B The cycle of life is in reasonably stable balance.

C A great variety of life is present, but no one species or type predominates.

D The organisms present are adjusted to the normal ranges of physical and chemical factors characteristic of the region, such as the following:

1 The latitude, turbidity, typical cloud cover, etc. affect the amount of light penetration and hence photosynthesis.

2 The slope, cross sectional area, and nature of the bottom affect the rate of flow, and hence the type of organisms present deposition of sludge, etc.

3 The temperature affects both certain physical characteristics of the water, and the rate of biological activity (metabolism).

4 Dissolved substances naturally present in the water greatly affect living organisms (hard water vs. soft water fauna and flora).

E Clean water zones can usually be characterized as follows:

1 General features:

a Dissolved oxygen high

b BOD low

c Turbidity low

d Organic content low

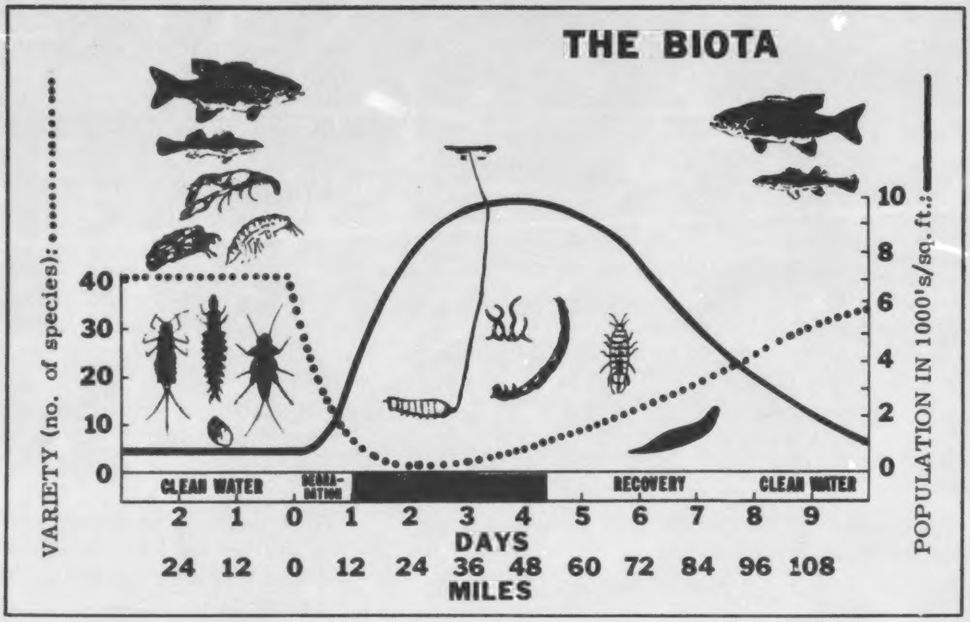


Figure 1: Relations between variety and abundance (production) of aquatic life, as organic pollution (discharged at mile 0) is carried down a stream. Time and distance scales are only relative and will be found to differ in nearly every case. After Bartsch and Ingram.[1]

- e Bacterial count low
- f Numbers of species high
- g Numbers of organisms of each species moderate or low
- h Bottom free of sludge deposits

2 Characteristic biota includes a wide variety of forms such as:

- a A variety of algae and native higher (vascular, or rooted) plants
- b Caddis fly larvae (Trichoptera)
- c Mayfly larvae (Ephemeroptera)
- d Stonefly larvae (Plecoptera)
- e Damselfly larvae (Zygoptera)
- f Beetles (Coleoptera)
- g Clams (Pelecypoda)
- h Fish such as:
  - Minnows (Notropid types)
  - Darters (Etheostomatidae)
  - Millers thumb (Cottidae)
  - Sunfishes and basses (Centrarchidae)
  - Sauger, yellow perch, etc. (Percidae)
  - Others

3 Organisms characteristic of clean lakes, estuaries, or oceanic shores might be substituted for the above, and likewise in the following sections. However, it should be recognized that no single habitat is as thoroughly understood in this regard as the freshwater stream.

III POLLUTION

A With the introduction of organic pollution (Figure 1, day 0), a succession of fairly well organized events are initiated. Important items to observe in interpreting the pollutional significance of stream organisms are the following:

B Numbers of species present, they tend to decrease with pollution.

C Numbers of individuals of each species tends to increase with pollution.

D Ratios between types of organisms are disturbed by pollution.

1 Clean water species intolerant of organic pollution tend to become scarce and unhealthy.

2 Animals with air breathing devices or habits tend to increase in numbers.

3 Scavengers become dominant

4 Predators disappear

5 Higher plants, green algae, and most diatoms tend to disappear.

6 Blue green algae often become conspicuous

E The importance of observations on any single species is very slight.

IV THE ZONE OF RECENT POLLUTION

A The zone of recent pollution begins with the act of pollution, the introduction of excessive organic matter: food for microorganisms (Figure 1, day 0)

B There follows a period of physical mixing.

C Many animals and plants are smothered or shaded out by the suspended material.

D With this enormous new supply of food material, bacteria and other saprophytic microorganisms begin to increase rapidly.

E The elimination of intolerant predatory animals allows the larger scavengers to take full advantage of the situation.

F This explosive growth of organisms, particularly fungi and bacteria, draws heavily on the free dissolved oxygen for respiration, and may eventually eliminate it.

G The number of types of organisms diminishes but numbers of individuals of tolerant types may increase.

H Zone of degeneration, or recent pollution, can usually be characterized as follows:

1 General features:

a DO variable, 2 ppm to saturation

b BOD high

c Turbidity high

d Organic content high

e Bacterial count variable to high

f Number of species declines from clean water zone

g Number of organisms per species tends to increase

h Other: Slime may appear on bottom

2 Characteristic biota:

a Fewer higher plants, but rank heavy growth of those which persist

b Increase in tolerant green, and blue green algae

c Midge larvae (Chironomidae) may become extremely abundant

d Back swimmers (Corixidae) and water boatmen (Notonectidae) often present

e Sludge worms (Tubificidae) common to abundant.

f Dragonflies (Anisoptera) often present have unique tail breathing strainer

g Fish types, eg:

- Fathead minnows (Pimephales promelas)
- White sucker (Catostomus commersonni)
- Bowfin (Amia calva)
- Carp (Cyprinus carpio)

V THE SEPTIC ZONE

A The exact location of the beginning of the septic zone, if one occurs, varies with season and other circumstances. (Figure 1, day 1)

B Lack of free DO kills many microorganisms and nearly all larger plants and animals, again replenishing the mass of dead organic material.

C Varieties of both macro and microorganisms and adjustable types (facultative) that can live in the absence of free oxygen (anaerobic) take over.

D These organisms continue to feed on their bonanza of food (pollution) until it is depleted.

E The numbers of types of organisms is now at a minimum, numbers of individuals may or may not be at a maximum.

F The septic zone, or zone of putrefaction can usually be characterized as follows:

1 General features:

a Little or no DO during warm weather

b BOD high but decreasing

c Turbidity high, dark; odoriferous

d Organic content high but decreasing

  - e Bacterial count high
  - f Number of species very low
  - g Number of organisms may be extremely high
  - h Other: Slime blanket and sludge deposits usually present, oily appearance on surface, rising gas bubbles

2 Characteristic biota:

  - a Blue green algae
  - b Mosquito larvae
  - c Rat-tailed maggots
  - d Sludge worms (Tubificidae and similar forms). Small, red, segmented (annelid) worms seem to be characteristic of this zone in both fresh and salt waters, the world around.
  - e Air breathing snails (Physa for example)
  - f Fish types: None

3 Note: Fortunately, all polluted waters do not always degenerate to "septic" conditions.

VI THE RECOVERY ZONE

A The septic zone gradually merges into the recovery zone. (Figure 1, day 4)

B As the excessive food reserves diminish so do the numbers of anaerobic organisms and other pollution tolerant forms.

C As the excessive demand for oxygen diminishes, free DO begins to appear and likewise oxygen requiring (aerobic) organisms.

D As the suspended material is reduced and available mineral materials increase due to microbial action, algae begin to increase often in great abundance.

E Photosynthesis by the algae releases more oxygen, thus hastening recovery.

F Since algae require oxygen at all times for respiration (like animals), heavy concentrations of algae will deplete free DO during the night when it is not being replenished by photosynthesis.

G Consequently this zone is characterized by extreme diurnal fluctuations in DO.

H With oxygen for respiration and algae, etc. for food, general animal growth is resumed.

I The stream may now enter a period of excessive productivity which lasts until the accumulated energy (food) reserves have been dissipated.

J Zone of recovery may usually be characterized as follows:

1 General features:

  - a DO 2 ppm to saturation
  - b BOD dropping
  - c Turbidity dropping, less color and odor
  - d Organic content dropping
  - e Bacterial count dropping
  - f Numbers of species increasing
  - g Numbers of organisms per species decreasing, (with the increase in competition)
  - h Other: Less slime and sludge

2 Characteristic biota

  - a Blue green algae
  - b Tolerant green flagellates and other algae
  - c Rooted higher plants in lower reaches
  - d Midge larve (Chironomids)

e Black fly larvae (Simulium)

f Giant water bugs (Belostoma spp.)

g Clams (Megalonais)

h Fish types:

- Green sunfish (Lepomis cyanellus)
- Common sucker (Catostomus commersonni)
- Flathead catfish (Pylodictis olivaris)
- Stoneroller minnow (Campostoma anomalum)
- Buffalo (Ictiobus cyprinellus)

3 Excessive production and extreme variability often characterize middle and lower recovery zones.

4 Unfortunately, many waters once polluted never completely "recover". Repollution is the rule in many areas so that after the initial pollution, clear out delineation of zones is not possible. Characterization of these waters may involve such parameters as productivity, BOD, some "index" figure, or other value not included here.

VII CLEAN WATER ZONE

A Clean water conditions again obtain when productivity has returned to a normal, relatively poor level, and a well balanced varied flora and fauna are present. (Figure 1, day "10") Conditions may usually be characterized as follows:

B General features: similar to upstream clean water except that it is now a larger stream.

C Characteristic biota: similar to upstream clean water fauna and flora except that species include those indigenous to a larger stream.

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SIGNIFICANCE OF EUTROPHICATION

I INTRODUCTION

A Eutrophication may be defined briefly as enrichment (of the aquatic environment) leading to the production of aquatic life. It is part and parcel of the process of natural self-purification.

B Productivity is defined briefly as the ability of water (or land) to produce a crop of living things.

C A baseline assumption of the present discussion is the absence of toxicity.

II NATURAL EUTROPHICATION

A Eutrophication may occur naturally in the course of geologic time.

B The classic example is a "pot-hole" lake formed when a large block of glacial ice (which had been buried in sand and gravel) melted.

1 At the outset, it was a barren hole in a vast gravel plain filled with ice water.

2 Life quickly became established as bacteria and algae drifted in. The nutrient base at this time was the inorganic dissolved solids in water.

3 As time went on, dead organic matter began to accumulate on the bottom as ooze. Rooted vegetation crept in around the shore. Leaves, sticks, and other dead organic matter accumulated around the margins until a mat of sod and peat began to build out from the shores. This overgrowth continued until the water was closed over and bog resulted. Bog grew into solid soil and the lake disappeared forever.

4 The processes of eutrophication therefore led to the self-elimination of the lake by means of organic matter essentially produced within its own confines and the immediate environs.

C All natural eutrophication does not necessarily lead to the elimination of water basins; other geologic processes often intervene. But it is interesting to note that vast quantities of carbon, hydrogen, and oxygen have been immobilized in the earth's crust as coal and peat measures as the result of eutrophication and biological productivity in the Carboniferous (late Paleozoic). Streams may have a natural productivity resulting from materials leached from bed rock or other materials.

III EUTROPHICATION BY MAN

A Covert (Concealed) Eutrophication via Soil Seepage

1 This is a slow but sure route for much nutrient material deposited in or on the ground to reach open water.

2 A limited(?) and unknown amount of production occurs in the subterranean environment. This includes the growth of soil bacteria and other fungi, or animals, and does not generally result in the entrainment of additional energy content in the biomass (mass of organic substance).

3 Due to the generally low rate of water seepage through soil, visible eutrophication of open bodies of water by this route is likely to be slow to develop, and equally slow to dissipate, should the source be eliminated.

4 Examples could be cited from Florida to Washington and Maine to California. Sources of the nutrient are generally seepage from agricultural crop fertilization, or soil absorption from individual sewage disposal systems.

B Overt (Open) Eutrophication

1 Raw waste discharges of sewage, dairy wastes, food processing wastes, etc.

a Likely to be conspicuous, intermittent, and obnoxious.

b Often create nuisance zones in streams or lakes during which mineralization takes place.

c Environmental eutrophication cannot begin until mineralization has proceeded to a point where basic plant nutrients are available, although very heavy "consumer" growth (scavenger animals) may result from direct feeding on the waste itself.

2 Treated waste discharges

a Generally less environmentally traumatic than raw waste; nuisance zones less common.

b Conventional secondary treatment less damaging than primary treatment alone.

c Residual minerals and energy content still inevitably available for eutrophication.

3 Overt eutrophication generally more remediable and subject to control than covert.

a Waste flow is completely controllable (barring accidents), as compared to diffuse seepage through soil.

b The quantity of eutrophic material in a body of water at any given time is finite and degradable. Given time, without replenishment, it will be exhausted.

IV SIGNIFICANCE OF EUTROPHICATION

A A point of view such as a water quality objective, for example, is necessary for the evaluation of eutrophication.

1 Enrichment of a water supply reservoir is generally considered bad, as it usually leads to the development of blooms of plankton organisms causing tastes and odors, or the development of an anaerobic hypolimnion with accompanying H_2S and other problems.

2 Enrichment of a fishing lake is considered good to the point where maximum fish production can be obtained.

B Eutrophication exists in many degrees; a little may be good, too much may be bad.

C A little natural productivity (eutrophication) plus a little man-made productivity may lead to too much total productivity.

D Eutrophication is inexorable and inevitable. Once the basic ingredients have been dumped into a body of water, somewhere, sometime, they are sure to be assimilated by an organism and thus contribute to new growth. Burial in a sludge bank or discharge on a flood simply delays the result in time or changes the location.

E Deliberately encouraged, eutrophication may constitute a final stage in treatment.

V CONCLUSION

Eutrophication is neither good nor bad, but thinking makes it so! (Apologies to Shakespeare)

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POLLUTION OF THE MARINE ENVIRONMENT

I Estuaries are the hydrologic exit points for inland lakes and streams and the oceans are the receiving waters.

The accumulated pollution load of the entire central portion of the country is disgorged through them.

A Estuarine waters are thus essentially "river waters" near their heads merging seaward into typically marine waters. Mixtures of fresh and salt water are called "brackish."

B Bays and the open ocean are essentially similar in water characteristics but usually have distinctive patterns of water circulation.

C Approximately one third of the population of the U.S. (over 55 million people) lives on estuaries, and seven of the worlds ten greatest cities are on estuaries.

II MARINE WATERS AS RECEIVING WATERS

A Marine waters are extremely "hard," as compared to most inland waters. The total dissolved solids content is measured in terms of parts per thousand (‰) rather than parts per million.

1 Water from the open ocean ranges from 33-35 parts per thousand of total salinity by weight (33,000-35,000 ppm).

2 There is considerable readjustment of the dissolved solid ratios as inland waters mix with seawater.

a Some of the solids, suspended in river water, may be dissolved in oceanic water, whereas other materials may be precipitated and dropped as silt. There is thus a certain amount of "natural" siltation unrelated to man-made pollution.

b It has recently been established that much of the silt in certain estuaries is of oceanic origin. In others it is of river origin.

c Biological assimilation removes additional material from solution.

B There is a great (but not inexhaustible) capacity for dilution in the oceans.

1 Though we will probably never approach the assimilative capacity of the open oceans as a whole for the natural purification of sewage type wastes, severe local disturbances of the natural ecological balance (pollution) are legion in coastal areas.

2 Safe dilution limits for radioactive wastes appear to be definitely limited.

a The effects of conditions in abyssal depths on waste storage containers cannot currently be predicted.

b Oceanic water masses are known to turn over and major currents to change at long or presently unpredictable intervals.

c Long half-life radioactive isotopes could accumulate dangerously in the biota.

III EFFECTS OF ORGANIC OR SEWAGE-TYPE POLLUTION

These materials while detrimental, can eventually be metabolized by biological processes.

It should be noted that many brackish water forms, particularly those adapted to life in brackish marshes and tidal flats, are highly tolerant of variable conditions, often naturally including high organic content. These then might be expected to tolerate moderate amounts of organic pollution and could be listed as "facultative."

A Molluscs

1 Oysters (such as *Crassostrea virginica*) and mussels (such as *Mytilus edulis*) are attached and unable to move to overcome silt accumulation.

a Slow siltation results in upward elongation of existing individuals.

b Continuous accumulation of silt will prevent the attachment of young larvae.

c Organic pollution is usually sewage which not only eliminates oysters and mussels ecologically, but also renders them unacceptable for sanitary reasons.

d They seem to be able to tolerate considerable intermittent oxygen depletion.

2 The term "clam" includes such forms as the hardshell clam or quahog (*Mercenaria mercenaria*) and the softshell clam (*Mya arenaria*) of the Atlantic, and razor clam (*Siliqua patula*) and geoduck (*Panope generosa*) of the Pacific coasts.

a Being unattached and naturally active burrowers, these animals are able to overcome sheer siltation.

b Their sensitivity to oxygen depletion resembles that of the oyster.

3 Since clams and oysters are plankton feeders, it should be noted that they are particularly liable to the accumulation of radioactive wastes.

a Some radioactive isotopes are assimilated by certain algae and phytoplankton.

b As the bivalves feed on the plankton, these radioactive chemicals will in turn be assimilated by them.

c Details have yet to be worked out, but preliminary investigations have demonstrated the basic facts.

4 Some snails have known responses to pollution and other ecological factors.

a The mud snail (*Nassa spp.*) is often found on shallow tidal mud flats with high temperatures and high organic content.

b The European snail (*Bulla stricta*) is listed as being favored by pollution.

B Annelids

A type of annelid worm known as sludgeworms are found to be favored by severe organic pollution, even though anaerobic conditions may obtain. These are represented in freshwater by such genera as *Tubiflex* and *Limnodrillus* and in seawaters by *Spio fulginosus*, *Capitella capitata* and others.

1 Due to their possession of hemoglobin they are able to extract the last trace of available oxygen from polluted water, and there is good evidence that at least some of them may utilize bound oxygen under anaerobic conditions.

2 A variety of annelid worms often dominates the fauna of a polluted area, even when industrial wastes are prevalent.

3 Members of this group apparently feed actively on the organic mud or sludge itself.

C Heavy organic pollution will eliminate the macrofauna and flora of an estuary or ocean front, as in a freshwater river or lake, largely as a result of oxygen

Table II - Pollution Tolerance of Marine Organisms
(As reported by Von Wilhelm, 1916 and Mohr, 1952)

	Response to Pollution		
	Intolerant	Facultative	Favored
THALLOPHYTES			
Chlamydothrix			xx
Enteromorpha spp.		x	
Ulva spp.		x	
PROTOZOA (Ciliophora)			
Eutreptia			x
Vorticella (Campannla type)			x
Epistylis			x
Vaginicola			x
Euplotes			x
Stylonychia			x
Lacrymaria			x
PLATYHELMINTHES			
Plagiostoma girardi			xx
MOLLUSCS			
Bornia corbuloides			x
Capsa frigilis			x
Tapes aureus			x
Bulla stricta			x
Dirois verrucosa			x
Spurilla neapolitans			x
Mytilus edulia		x	
Cardium edule		x	
ANNELIDS			
Spio fulginosus			xx
Capitella capitata			xx
Arenicola claparedei & A. grubei			x
Hydroides pectineta & H. uncinata			x
Spirographis salanganis			x
Staurocephalua rudolphi			x
Sternaspis thalassimoides			x
ECHINODERMS			
Asterias tennispina		x	
BRYOZOA			
Bugula avicularia & B. calathus			x
Bugula purpurotincta			x
CRUSTACEA			
Nebalia golatea			x
Brachynotus sexdentatus			x
Balanus spp.		x	
TUNICATES			
Cione intestinalis			x
Botryllus aurolineatus			x
Box salpa		x	

x - indicates general degree of tolerance
xx - strongly favored

deficiency, or the physical accumulation of a sludge blanket on the bottom. Living matter, however, is represented by bacteria and molds. The impoundment of inactive water over such an area hastens this destructive process.

1 As distance up or down the estuary provides time and dilution, biological oxidation and mineralization proceeds to the point where some elements of the macrofauna and flora can live.

2 These tolerant species, such as, those noted above, then take advantage of the increased concentration of nutrients and the lack of competitors to grow in size and numbers far beyond the natural production levels.

3 This then, is the same expression of recovery from organic pollution found in freshwater, namely: super abundance of life, but generally restricted variety.

D Marine fishes respond to pollution in essentially the same way as freshwater fishes.

1 Due to their being accustomed to moving about in larger bodies of water, they have more chance to avoid the proximity of local pollution sources.

2 Elimination of bottom organisms tends to discourage bottom feeding fish, although scavengers such as sculpins toadfish, and others may often be found in the vicinity of outfalls.

3 Organic sedimentation may directly smother the eggs of bottom spawning fishes such as smelt.

4 Severe pollution in a river-mouth or estuary may also serve as a block to sensitive anadromous fish seeking to run upstream to spawn.

5 Organic enrichment may provide more food and hence increase productivity on the fringes of polluted zones as in freshwaters.

6 Fish such as tarpon and mullet have been observed to thrive in highly enriched brackish water ponds and bays in Florida and elsewhere. This of course is essentially the same type of situation as a fertilized fish pond.

IV TOXIC POLLUTION

The physiological nature of the action of toxicants on organisms is infinitely varied and but partially understood. The adjustment of organisms to varying salinities may in some cases be related to toxicity through the phenomenon of osmosis.

A Organisms may be grouped with reference to their ability to endure salinity changes (Figure 1).

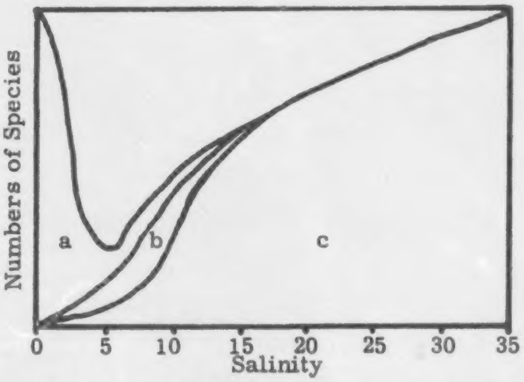

Figure 1. DISTRIBUTION OF ORGANISMS IN AN ESTUARY

a Euryhaline, freshwater
b Indigenous, estuarine, (mesohaline)
c Euryhaline, marine

1 Stenohaline organisms can endure relatively little variation in salinity.

2 Euryhaline organisms can endure considerable variation in salinity.

3 Freshwater organisms having a body containing fluid of a higher osmotic pressure than that of the surrounding media must constantly resist the tendency of that media to penetrate and dilute their body fluids.

4 Marine organisms having a body containing fluid closely resembling the surrounding media, is either in osmotic equilibrium with his surroundings, or may even have to take in extra water to prevent dehydration.

5 Osmotic differences associated with the salinity gradient may play a significant role in determining the toxicity of a given waste at different parts of an estuary. Detergent, for example, has been found to be more toxic in marine waters than in freshwater.

B Outfalls discharging toxic wastes may often be recognized by completely denuded environs.

C Toxic wastes are sometimes eliminated from the water by complexing on suspended material. When this material is deposited, the toxicants may be removed from the waters, but they are deposited in the substrate. Such a situation may often be recognized by a pauperate bottom infauna or epifauna, while the overlying water shows no biological effect. Gradual recovery of the bottom fauna usually takes place with increasing distance from the outfall, provided there are no complicating factors.

D Pollution dilution by sewage. A situation has been observed where the generally toxic waters of an estuary are diluted by the outfall of a domestic sewage treatment plant to such an extent that a limited fauna is able to survive in the vicinity of the sewage outfall.

V SOME PRACTICAL CONSIDERATIONS OF MARINE AND ESTUARINE WASTE DISPOSAL

A Due to the lesser specific gravity of sewage, it has a strong tendency to channel its way to the surface of salt water, with relatively little mixing enroute unless very well diffused at the point of discharge. On the surface it is susceptible to wind drift. If this is onto a bathing beach from an offshore outfall, sanitary conditions may quickly become intolerable.

B Of major significance is the absence of a continuous unidirectional current to remove material from the outfall and immediately begin mixing and dilution. This is of course likewise true of lakes.

1 Oceanic surface currents may be strongly wind influenced, or associated with tidal cycles.

2 Currents in bays and estuaries are at best tidal. Use is sometimes made of this by constructing temporary holding basins and then dumping only on selected phases of the tidal cycle.

3 Estuarine circulation patterns are affected by several factors.

a Tides impart an "in and out" motion to the water (as mentioned elsewhere).

b Inflowing freshwater imparts an "out motion." The resultant of these two is known as the "net tidal drift."

c Typically, cross sectional areas increase as the sea is approached. This reduces the net tidal drift.

d The denser sea water tends to flow in underneath the lighter freshwater in the mixing process.

e The coriolis effect pulls moving bodies to the right (in the northern hemisphere). Although this is insignificant in most river situations, it results in generally lower salinities along the right hand (facing the ocean) shores of estuaries which are not too irregular in shape, as the river water moves down, and higher salinities along the left hand shores as the sea water moves in. This can be seen in such situations as the Chesapeake Bay in Maryland.

f Irregularities of bottom and shore and wind action all combine to complicate and confuse the results of these forces.

4 Careful study of local hydrographic circulation will sometimes reveal other ways in which these phenomena can be put to advantage.

C The physical difficulty of constructing offshore oceanic outfalls which will withstand the rigors of the storm, ice, and shifting sand renders this an extremely expensive undertaking.

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WATER TEMPERATURE AND WATER QUALITY

I INTRODUCTION

A Temperature is the basic variable in water "climates".

1 Temperature, or the amount of thermal energy present, is originally of solar or cosmic origin. Biological processes acting over geologic time temporarily capture and store much energy in organic substance. The "fossil fuels" (oil, gas, and coal) which we burn today release solar energy captured in the geologic past, which but for man might not have been released until sometime in the geologic future. Most of the solar energy being captured today, is released probably today, with the possible exception of some unrecognized fraction which is proceeding into long term storage.

The release of atomic energy is of inorganic or cosmic origin, and the magnitude and significance of the additional thermal discharge to the environment has yet to be accessed.

One last observation is important before turning to the details of water temperature and water quality. While we are most critically occupied with the immediate or local impact of a concentration of thermal energy released at a given point in the environment (the excess or "waste" which man is unable to capture and entrain in his electric transmission lines), it should be remembered that of every ton of coal or pound of uranium burned as fuel, nearly 100% of the energy contained eventually finds its way into the general global environment. A small remaining fraction is rebound as chemical energy in some "product."

2 Direct solar radiation is the overriding contributor of thermal energy to all lands and waters.

a Total energy from insolation onto "spacecraft earth" is counterbalanced by the radiation of terrestrial energy into space. If the two do not exactly balance on an annual basis, the overall temperature (climate) of the earth will rise or fall.

b The annual climate or heat budget of a given body of water is determined by its geographic location (latitude elevation, etc.) interacting with local meteorological conditions, and other factors.

c There is, therefore, a natural or normal temperature regimen for any given body of water to which it will tend to return if disturbed by man.

d There is, also, a normal or characteristic community of aquatic organisms that will tend to persist. When the heat budget or climate of a body of water is changed, the fauna and flora change.

3 There is great diversity of opinion, even among knowledgeable people, as to the effects of thermal changes in waters. Some of the reasons for this follow:

a Only a continuously maintained temperature of 100° C could keep a surface water mass sterile. The question is therefore not: life or no-life; but rather: what kind of life is the objective?

b Aquatic life has received more attention than other water uses because the aquatic organisms cannot escape the water conditions.

c There are certain circumstances in which a modest rise in temperature might be considered to be beneficial as for example: keeping an area of a river or a harbor free of ice for navigation, or winter fishing. There has, also, been investigation of the use of warmed waters for certain aspects of aquaculture.

d It is, therefore, important in discussing the virtues and vices of thermal changes to clearly define or specify the objective or type of aquatic community in mind.

4 It is clear that the need for more and more power will continue into the foreseeable future (Table 1).

B Human activities which may modify receiving water temperatures include the following:

1 Logging and other land stripping activities which increase the rate of surface run-off and hence raise or lower temperatures of influent waters, depending on the season.

2 Removal of stream bank shade

3 Erosion which fills in stream bed and causes water to be spread in broad shallow layer, exposed to sun and air.

4 Release of cold waters from hypolimnion of deep reservoirs.

5 Withholding or augmenting flow by dam manipulation.

6 Release of relatively large volumes of high temperature wastewaters from power production and/or industrial processes.

II THERMAL ELECTRIC POWER PRODUCTION AS A STREAM WARMING ELEMENT

A Production of electric power by stream plants involves the wastage of considerable quantities of energy in cooling waters. Approximately 5000 BTU of heat are wasted for each kilowatt of electricity generated. This represents an efficiency of roughly 40%.

B It is estimated that approximately 80% of all energy required in the future will come from steam generating plants.

C Weirs and jetties help greatly in the dispersal of warmed waters, but must be carefully designed to each situation.

D As water temperature rises, its value as a coolant diminishes.

E Heat dissipation from a body of water which has been heated above its equilibrium temperature with the meteorological conditions follows Newton's Law of Cooling which states that the rate of cooling is proportional to the difference between the temperature of the body of water, and the equilibrium temperature for the given meteorological conditions. For example, an analysis of the Ohio River as at Cincinnati has shown that it would require over 200 miles to dissipate 99 + % of heat added (Figure 1).

III EFFECTS OF HEAT ON ORGANIC WASTE DISPOSAL

A Higher temperatures accelerate the rate of bacterial growth, the optimum temperature being in the range of 30° C (86° F).

1 As water temperatures approach this value, the rate of BOD thus approaches a maximum.

TABLE 1

MAXIMUM TEMPERATURES PROBABLY COMPATIBLE WITH THE WELL-BEING OF VARIOUS SPECIES OF FISH AND THEIR ASSOCIATED BIOTA IN °C

Temperature	Taxa
34 C	Growth of catfish, gar, white or yellow bass, spotted bass, buffalo, carpsucker, threadfin shad, gizzard shad
32 C	Growth of largemouth bass, drum, bluegill, crappie
29 C	Growth of pike, perch, walleye, smallmouth bass, sauger, California killifish, topsmelt
27 C	Spawning and egg development of catfish, buffalo, threadfin shad, gizzard shad, California grunion, opaleye, northern swellfish
24 C	Spawning and egg development of large-mouthed bass, white and yellow bass, spotted bass, sea lamprey, alewife, striped bass
19 C	Growth or migration routes of salmonoids and for egg development of perch, smallmouth bass, winter flounder, herring
12 C	Spawning and egg development of salmon and trout (other than lake trout)
9 C	Spawning and egg development of lake trout, walleye, northern pike, sauger, and Atlantic salmon

2 If the waste assimilative capacity of a stream is being utilized based on a given stream temperature, and the temperature subsequently raised, the DO may drop so low as to produce fish kills and other nuisance conditions.

B Higher water temperatures may, also, lead to a higher concentration of bacteria pathogenic to man.

IV EFFECTS OF HEAT ON FISH AND OTHER AQUATIC LIFE

A Vulnerability of fish and other aquatic life to high temperatures represents a major restriction on the discharge of cooling water.

1 Involves duration of exposure as well as absolute thermal level.

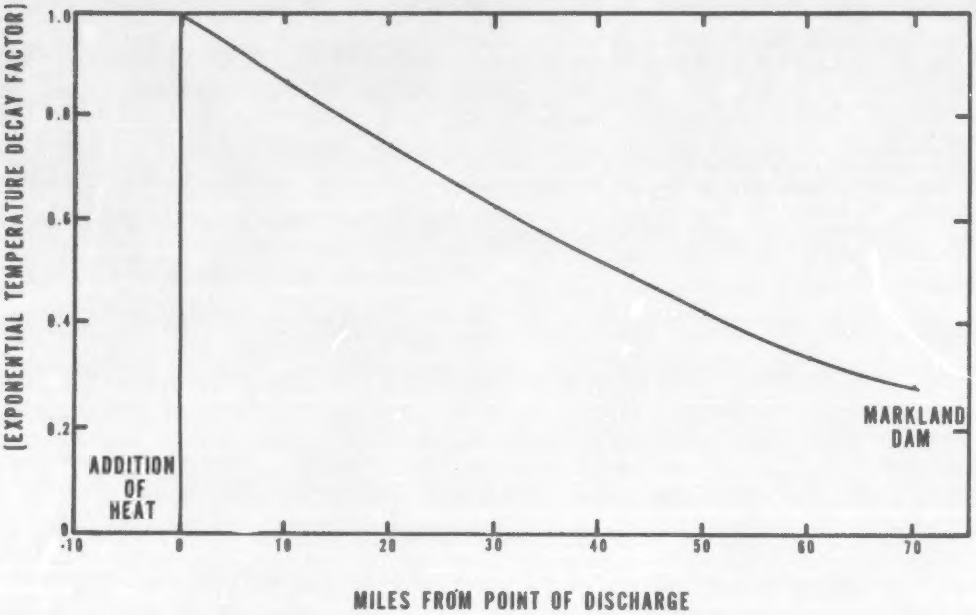
2 Sensitivity to toxic substances is increased.

3 Lower temperatures are required in winter than in summer.

B Factors contributing to the sensitivity of fish to heat

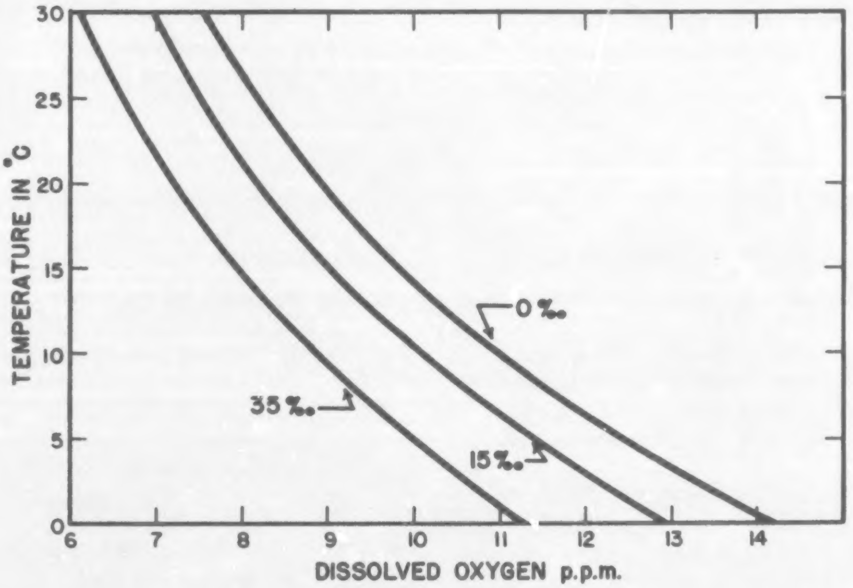
1 Oxygen solubility diminishes as temperature rises (Figure 2).

2 Oxygen requirements of aquatic life increase as temperature rises (Figure 3).



TEMPERATURE DROP THROUGH MARKLAND POOL
OHIO RIVER

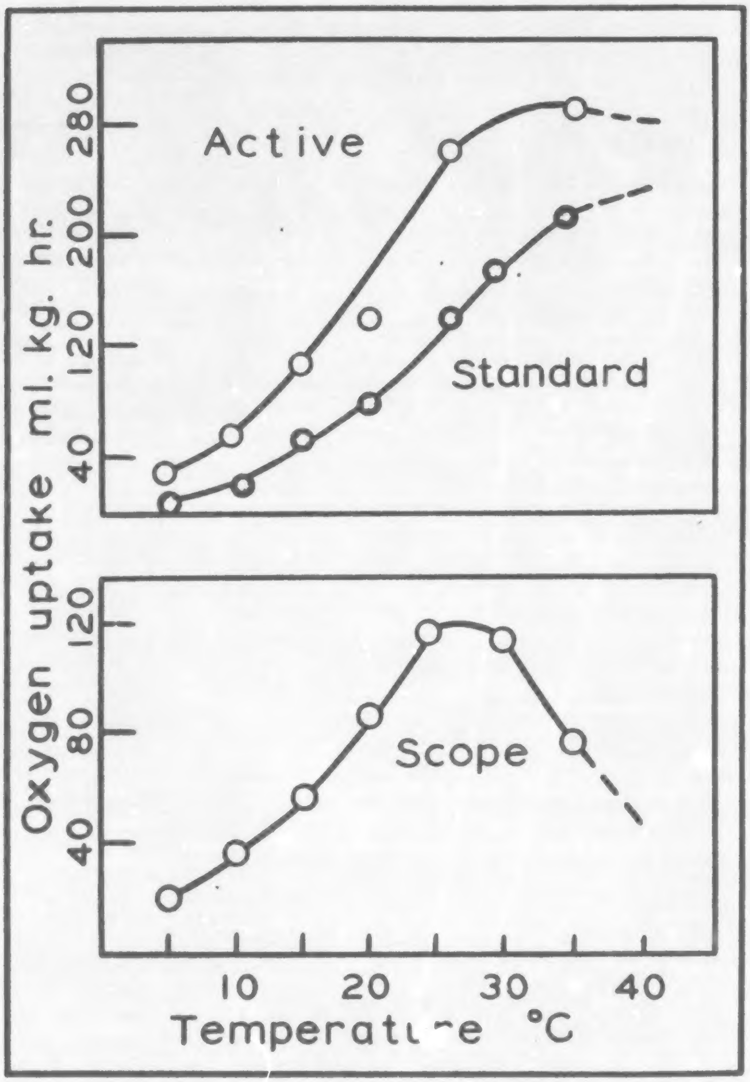
Figure 1



OXYGEN SOLUBILITY AT SELECTED SALINITIES

RICHARDS AND CORWIN, LIMNOLOGY AND OCEANOGRAPHY, 1956 BI.ECO.9c.2.58

Figure 2

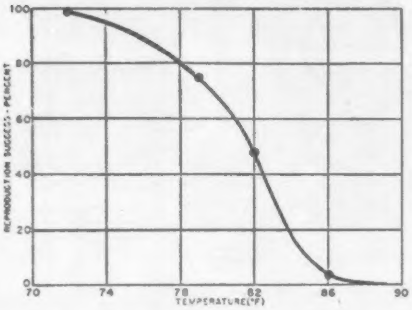


THE RELATION OF TEMPERATURE TO ACTIVE AND STANDARD METABOLISM IN YOUNG GOLDFISH OF AN AVERAGE WEIGHT OF 2 GM. From Fry and Hart (1948)

Figure 3

3 The sensitivity of aquatic organisms to temperature levels and changes varies with age, size, and size.

a A constant elevated temperature reduces the potential of fish to reproduce (Figure 4).



EFFECTS OF CONSTANT TEMPERATURE ON REPRODUCTION OF A MINNOW (Pimephales promelas)

Figure 4

b Different species have different preferred temperature ranges.

c Seasonal cooler temperatures are often essential to egg production and hatching, while warmer summer temperatures will promote faster growth after hatching, up to some limit of tolerance characteristic of the species.

4 Lethal high temperatures as determined in laboratory tests vary widely for different species, e.g. goldfish: 107.6° F, pink salmon: 75° F.

a Lethal temperatures differ at different times of the year, as well as for the different life history stages (Figure 5).

b This is analogous to a temperature of 50° F for man: in winter it feels "warm," in summer it is "cool."

5 Sudden changes in water temperature can be fatal to certain organisms, both fish and fish food organisms.

6 Acclimatization to higher temperatures is faster than to lower. Fish acclimated to warm water are rapidly killed when they swim into cold water. This implies that the sudden shutdown of a thermal discharge may be more detrimental than a continuous normal discharge.

7 Reduction in DO, increase in CO_2, or the presence of toxic materials reduces maximum tolerable temperatures.

8 Species can be eliminated at less than lethal temperatures by predators, parasites, or diseases which are less temperature-sensitive.

9 Some fish do not seem to be able to avoid killing hot waters, while others do.

10 Preferred temperature ranges in laboratory tests generally are somewhat higher than in field observations (Figure 6). This may be influenced by the demands of the natural environment for greater activity and hence a need for more oxygen (Figure 2, Table 1).

11 Temperature can act as a directive force in fish migration.

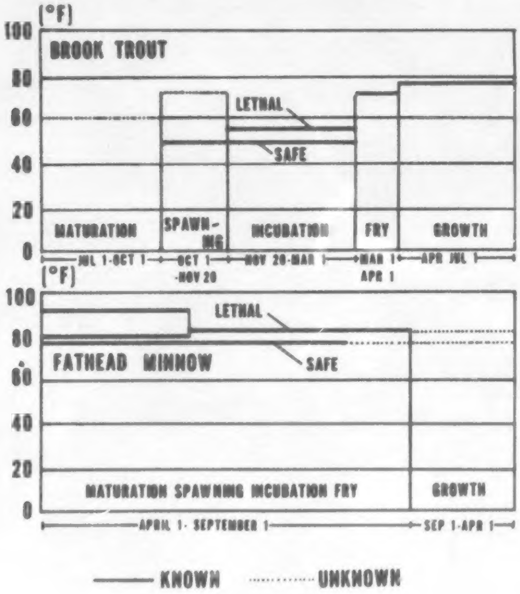
12 The exact physiological mechanisms of heat kill are not fully understood.

Fats rather than proteins seem to be the most critical substance.

a Some fish will die at temperatures of 65° F, lower than that at which proteins usually coagulate.

b Tropical (or heat-adapted) plants and animals often have fats with a higher melting point than arctic (or cold-adapted) organisms.

c Animals (such as goldfish) fed high melting point fats (e.g. beef) develop higher melting point body fats than those fed on low-melting fats (such as fish oil). They are in turn able to tolerate higher temperatures.



THERMAL TOLERANCE OF CRITICAL LIFE HISTORY STAGES

Figure 5

d Lethal temperatures seem to destroy fat-calcium relationships.

C Effects of Temperature on Fish Food Organisms

1 Species composition and abundance are affected in ways similar to the fishes as outlined above.

2 Warm waters encourage blue-green algae. Some can tolerate as high as 185° F for limited periods (Figure 7).

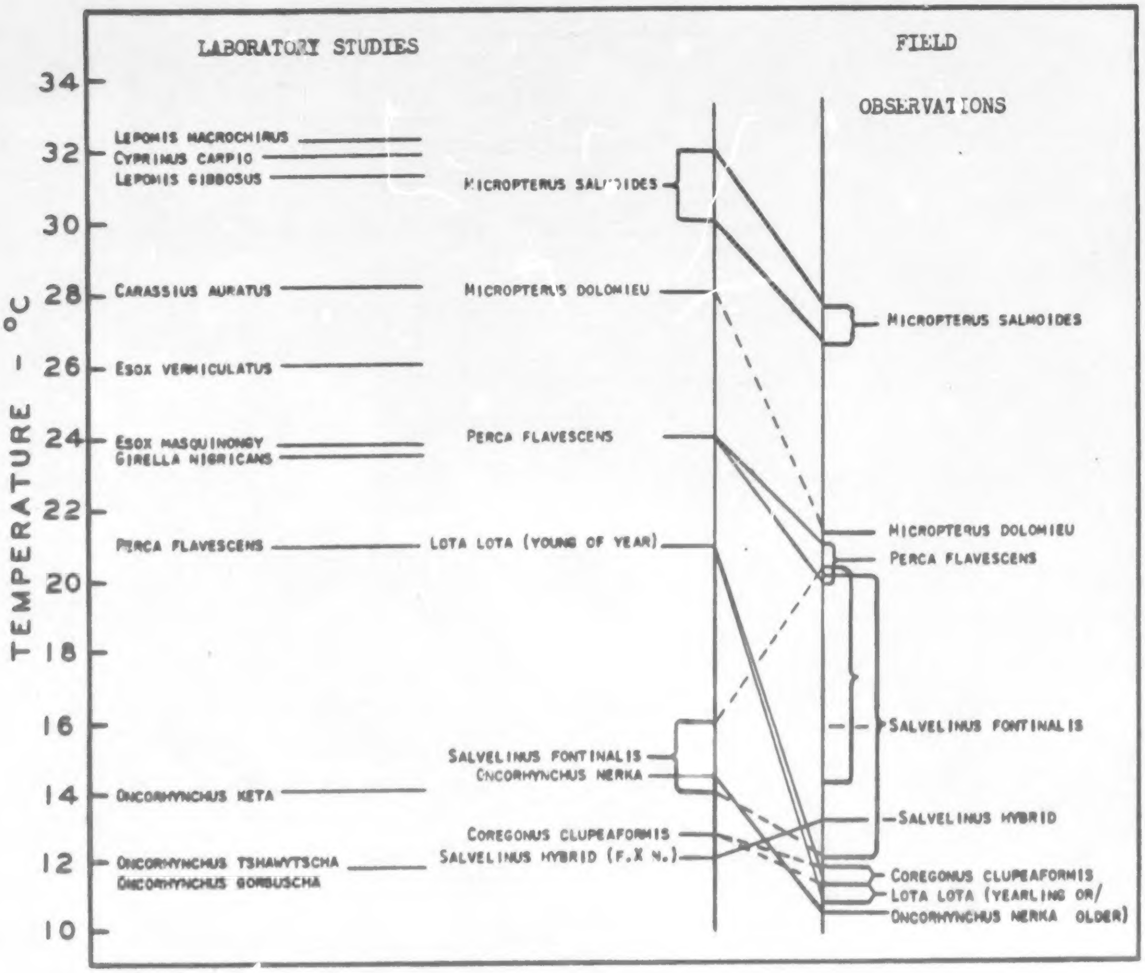
3 A temperature increase of 8° C stimulated photosynthesis in phytoplankton in one series of observations when ambient water temperatures were 16° C or cooler, but inhibited photosynthesis when natural waters were 20° C or warmer. The existence of a diurnal response to thermal stimulation was noted at 9:00 A.M.

4 Warmed waters speed up life cycles and encourage year round emergence of aquatic insects, often creating local nuisance conditions.

V MARINE, ESTUARINE, AND ANADROMOUS SPECIES

A The general principles of biotic responses to thermal conditions outlined above apply as well to salt water forms as to fresh.

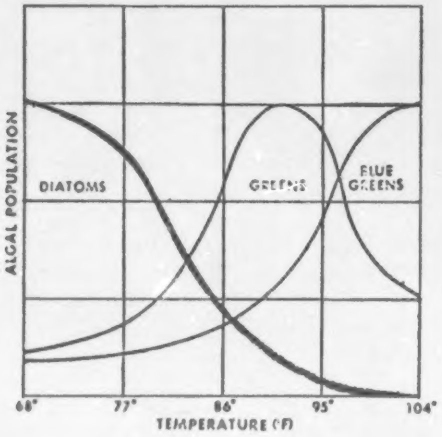
B Salmon do not feed during the spawning migration, hence higher temperatures may so increase their metabolic demands as to deplete their food reserves before spawning can occur. A thermal block at the mouth of a river (e.g. 21.1° C at the mouth of the Okawogan River in Washington) can prevent an entire spawning run.



Left. A comparison of various final preferenda as found by laboratory studies.

Right. A comparison of field observations with laboratory results for a number of species.

Figure 6



EFFECT OF TEMPERATURE ON TYPES OF PHYTOPLANKTON

Figure 7

1 The American Oyster Crassostrea Virginica may spawn, depending on its condition, at temperatures from 15 to 34° C, spawning being triggered by a rise in temperature.

2 The shore crab Carcides Maenas thrives, but does not breed at temperatures between 14 and 28° C. Breeding can only take place outside the heated area.

C Fish in the estuarine environment are more susceptible to temperature changes than those in fresh water. However, wider ranges of tolerance between species exist.

D Most shellfish (in the broad sense: mollusca and crustaceans) are relatively or highly stenothermal (unadaptable to rapid temperature changes). Some are stenothermal for one stage (e.g. spawning), and eury-thermal for others (e.g. growing).

Preliminary observation, also, indicates that heat stress may stimulate oysters to accumulate copper (as other stressful factors are known to do) without being a direct killing agent.

E The distribution of many benthic invertebrate organisms is temperature dependent (See Table 2).

ENVIRONMENTAL TEMPERATURE RANGES OF SOME MARINE INVERTEBRATES

Table 2

Taxa	Temperature range in ° C
American Oyster	4 - 34
European Oyster	0 - 20
Opossum Shrimp	0 - 31

F Observations in Miami, Florida indicate that the following groups of larger plants may show temporary or permanent changes following thermal discharge:

1 The sea grass Thalassia, an important habitat for invertebrates and stabilizes of the substrate.

2 Certain macro-algae

(Lurencia, Fucus, Laminaria, Macrocystis, Halimeda, and Acetabularia)

3 The phytoplankton (see Figure 7)

4 The epiphytic micro-algae

5 The benthic micro-algae

G The upper limits of thermal tolerance for two species of copepods from Chesapeake Bay were found to be near the normal temperature of the habitat during the summer. The addition of chlorine to the cooling water killed all copepods passing through the system at temperatures below the upper limits of thermal tolerance.

Dry weight of total estuarine epifauna production averaged 2.8 times greater in the discharge canal than in the intake area over a 5 year period in another study.

VI SUMMARY

The various environmental factors cannot be considered as isolated entities, organisms respond to the entire environment. Temperature criteria thus must be based on the requirements of the entire aquatic population, and on the life history requirements for different seasons of the year.

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BIOTIC EFFECTS OF SOLIDS

I Sedimentation of rivers, lakes, estuaries and adjacent coastal water should be considered as a special case of pollution resulting from deforestation, overgrazing and faulty agricultural practices, road construction, and all other land management abuses.

A Good farming practices can do a great deal to prevent silt from reaching streams and lakes.

B Road building and housing development projects, placer mining, strip mining, coal and gravel washing, and unprotected road cuts are important sources of turbidity that can be reduced with planning, good housekeeping, and regulation.

II Setteable solids include both inorganic and organic materials which may settle out rapidly, forming bottom deposits of both inorganic and organic solids.

A They may adversely affect fisheries by covering the bottom of the stream or lake with a blanket of material that destroys the bottom fauna or the spawning grounds of fish (Figure 1 from Ingram, et al).

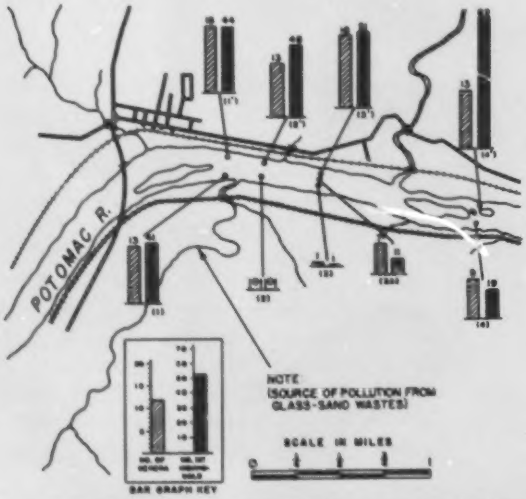

Figure 1 Vertical bar graphs, superimposed over a map, used to show total genera and individuals of bottom animals per unit area

B The organic fraction includes such setteable materials as greases, oils, tars, animal and vegetable fats, feed lot wastes, paper mill fibers, synthetic plastic fibers, sawdust, hair, greases from tanneries, and various settleable materials from city sewers. Deposits containing organic materials may deplete bottom oxygen supplies and produce hydrogen sulfide, carbon dioxide, methane, or other noxious gases.

C The inorganic components include sand, silt, and clay originating from such sources as erosion, placer mining, mine tailing wastes, strip mining, gravel washing, dusts from coal washeries, loose soils from freshly plowed farm lands, highway, and building projects.

D Some settleable solids may cause damage by mechanical action.

E The biota of streams is limited by the type of substrate.

1 A depositing substrate generally contains fewer types and may be dominated by burrowing forms.

2 An eroding substrate has a characteristic fauna of sessile attached and foraging members, such as bryozoans, stoneflies, nonburrowing mayflies, and net-spinning caddis flies.

3 The addition of solids over an originally eroding riffle substrate will produce pronounced changes in the biological community all the way from diatoms to fish. The following are common macroinvertebrates of this new "trickling filter" community in contrast to E 2 above.

a Oligochaetes

b Alderfly larvae (Sialis)

c Midge larvae (Chironomids)

III Turbidity, color, and transparency are closely interrelated phenomena in water. They must be observed simultaneously because transparency is a function of turbidity, water color, and spectral quality of transmitted light.

A Turbidity is an expression of the optical property of a sample of water which causes light to be scattered and absorbed rather than transmitted in straight lines through the sample.

B Turbidity is caused by the presence of suspended matter such as clay, silt, finely divided organic matter, bacteria, plankton, and other microscopic organisms.

1 Algae, turbidity from silts and clays, and color of the water all affect one environmental factor of major importance in the productivity of aquatic wildlife habitat--light penetration of the water.

a Excessive turbidity reduces light penetration in the water and, therefore, reduces photosynthesis by phytoplankton organisms, attached algae, and submersed vegetation.

b The results of many of man's activities, including agriculture, industry, navigation, channelization, dredging, land modification, and eutrophication from sewage or fertilizers, often reduce light transmission to the degree that aquatic angiosperms of value to wildlife cannot grow.

c Mixed effluents from various industrial plants and domestic sewage increase the turbidity of receiving water. It is difficult to distinguish between the effect of the attenuation of light due to suspended particles and the direct effect of the particles in suspension on the growth physiology of aquatic organisms.

2 In many coastal waters, the principal cause of turbidity is the discharge of silt carried out by the principal rivers. Secchi disc readings show that the transparency of water at the mouths of large rivers during flood stage may be reduced to a few centimeters. At normal river stages, the disc may be visible at several meters below the surface.

3 Dredging of bays and tidal rivers for improvement of navigation occasionally presents serious problems. Benthic communities in the area near dredging operations may be destroyed or damaged by spoil deposition, increase in water turbidity, release of toxic substances accumulated in the mud of the polluted areas, and by changing the pattern in the dredged area.

IV PHYSICAL DAMAGES FROM SILTATION

A Silt and sediment are particularly damaging to gravel and rubble-type bottoms. The sediment fills the interstices between gravel and stones, thereby eliminating the spawning grounds of fish and the habitat of many aquatic insects and other invertebrate animals such as mollusks, crayfish, fresh water shrimp, etc.

B Accumulation of silt deposits is destructive to marine plants, not only by the associated turbidity, but by the creation of a soft, semi-liquid substratum inadequate for anchoring the roots. Back Bay, Virginia and Currituck Sound, North Carolina serve as examples of the destructive nature of silt deposition. Approximately 40 square miles of bottom are covered with soft, semi-liquid silts up to 5 inches deep; these areas, constituting one-fifth of the total area, produce only 1 percent of the total aquatic plant production.

V SILT POLLUTION INCLUDES NOT ONLY PURELY PHYSICAL EFFECTS, BUT ALSO MAY INCLUDE COMPLEX MATERIAL.

A Pollution in the estuary may be derived from contamination hundreds of miles upstream in the river basin or it may be of purely local origin. Silt plays a major role in the transport of toxicants, especially pesticides, down to the estuary.

1 Agricultural chemicals are adsorbed on silt particles. Under poor farming practices, as much as 11 tons of silt per acre per year may be washed by surface water into a drainage basin.

2 Surface mining and deforestation further accelerate the process of erosion and permit the transport of terrestrial chemical deposits to the marine environment.

B Oil that settles to the bottom of aquatic habitats can blanket large areas and destroy the plants and animals of value of waterfowl.

1 Reportedly, some oil sludges on the bottoms of aquatic habitats tend to concentrate pesticides, thus creating a double hazard to waterfowl that would pick up these contaminants in their normal feeding process.

2 Observations on storage of carcinogenic compounds found in oil-polluted water and on affected sediments are biologically significant, since they may be concentrated by commercially harvested bivalves.

C Much of the tonnage of aerially applied pesticides fails to reach the designated spray areas and the presence of 5 μg/l of DDT in presumably untreated Alaskan rivers indicates the magnitude of this facet of the pollution problem.

1 The continuous presence of 5 μg/l of DDT in the marine environment would decrease the growth of oyster populations by nearly 50 percent.

2 Atmospheric drift is also an important factor in the transport of a variety of pollutants to the aquatic environment.

3 Organochlorine compounds from sources other than pesticides applications are involved in food webs and biological magnification in remote polar environments.

D "The data on water pollution, however, are less encouraging. Among other things, they indicate that land runoff from farms and even urban land, as opposed to discharges from cities and factories, has a much greater impact on water pollution than we realized. In all types of river basins, the concentration of nutrients, which can eutrophy our lakes, is increasing. These data indicate that while we carry on our major efforts to clean up pollution from municipal and industrial sources, we must increasingly turn our attention to land runoff of nutrients, fertilizers, pesticides, organic materials, and the soil particles that often transport the others. If we fail to do so, our expenditures for water quality will not achieve maximum improvement." Council on Environmental Quality.

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Descriptors: Aquatic Life, Benthos, Degradation, Turbidity, Runoff, Water Quality

EFFECTS OF POLLUTION ON FISH

I INTRODUCTION

A By what means do pollutants exert their effects?

B What is the relationship between water quality and water use by fishes?

C What is the reaction of fishes to domestic sewage?

D Is there any noticeable change in species composition of the population following pollution?

E Is there any genetic or environmental selection in favor of pollution resistant strains?

F Nearly any pollutant, given sufficient concentration and time, can kill as a direct toxicant. We are primarily concerned here with sub-lethal or chronic levels of pollutants. (Acute toxic levels and physiological mechanisms are treated elsewhere.)

II MECHANISMS OF DETRIMENTAL ACTION

A Inert silt may

1 Clog gills and smother eggs and fry,

2 Blind sight feeders and eliminate hiding places,

3 Smother food organisms,

4 Reduce oxygenation by smothering algae.

B Irritants may

1 Act as repellents,

2 Cause excessive mucous secretion and upset osmotic balance.

C Sub-lethal quantities of a host of environmental materials are constantly penetrating the bodies of fishes by various routes. We are generally not aware of their presence unless they:

1 Cause an observable effect on the fish,

2 Cause an effect on man by imparting off-taste or odor to fish flesh,

3 Are sought for and detected, e.g.; radioactive substances, DDT, mercury.

We can only speculate as to their undetected effects.

III ENVIRONMENTAL RELATIONSHIPS BETWEEN WATER QUALITY AND WATER USE BY FISHES

A Freshwater fishes sometimes spend their entire lives in a single body of water. Pollution of that body of water therefore impinges on them at every stage of their life cycle, and at every point in their various ecological relationships; such as, seeking food or escaping enemies.

B Migratory fishes on the other hand feed and grow up in one body of water (the ocean for anadromous species, fresh water for the catadronous eels), then travel a migration route (usually a river) to another body of water where they breed.

Pollution at either end of the route, or a pollution block along the migration route, may eliminate the species.

C What will affect one species adversely may be favorable for another.

1 Cold water species, such as various trouts, might be killed or eliminated by warmed water from a power plant which would in turn permit the survival of warm water species, such as certain basses, sunfishes, etc.

2 Benthic species (such as catfish, sculpins, or suckers, which live near the bottom) might be eliminated by a smothering

blanket of inert material which would not affect limnetic species inhabiting the open water areas (such as white and yellow bass, gizzard shad, or walleye). The limnetic species on the other hand might be inhibited by a dense turbidity which would hide their prey, suppress the growth of nutritious plankton, or clog their gills; this in turn being relatively harmless to the benthic group.

3 Likewise the shoreline hugging littoral forms (like pumpkinseed or bluegills) and profundal species (such as lake trout) might respond selectively to such factors as temperature or transparency.

IV RESPONSE OF FISHES TO SEWAGE AND SIMILAR WASTES

A These wastes in general are not toxic in themselves, but exert their effects on fishes directly.

B Oxygen Depletion

1 May lead to death at various stages in life history depending on circumstances.

2 May lower resistance to disease or increase sensitivity to intoxication.

3 May reduce ability to capture food or swim against current.

C May smother or kill normal food sources.

D May increase normal fish production through eutrophication.

E Usually changes normal population balance by driving out predatory types and encouraging scavengers.

F Reported to cause osteological and other pathological manifestations, such as the knothead condition of carps in the Illinois River.

V NATURAL SELECTION AND ACCLIMATIZATION TO POLLUTION

A Known biological mechanisms for selective breeding of pollution resistant strains operate in nature among fishes as among other organisms.

1 Studies of population genetics indicate that after some finite number of generations of population stress (e.g.; exposure to a given pollutant), permanent heritable resistance may be expected to develop.

2 If the environmental stress (or pollutant) is removed prior to the time that permanent resistance is developed in the population, reversion to the non-resistant condition may occur within a relatively few generations.

3 Habitats harboring populations under stress in this manner are often marked with the dead bodies of the unsuccessful individuals.

B Individual organisms on the other hand can over a period of time (less than one life cycle) develop a limited ability to tolerate different conditions, e.g.; pollutants:

1 With reference to all categories of pollutants both relatively facultative and obligate species are encountered (e.g.; euryhaline vs. stenohaline, eurythermal vs. stenothermal).

2 This temporary somatic acclimatization is not heritable.

C A given single-species collection or sample of living fishes may therefore represent one or more types of pollution resistance:

1 A sample of an original population which has been acclimated to a given stress in toto.

2 A sample of the surviving portion of an original population, which has been "selected" by the ability to endure the stress. The dead fish in a partial fish kill are that portion of the original population unable to endure the stress.

3 A sample of a sub-population of the original species in question which has in toto over a period of several generations developed a heritable stress resistance.

D Any given multi-species field collection will normally contain species illustrative of one or more of the conditions outlined above.

VI POPULATION COMPOSITION RESPONSES TO POLLUTION

A Sewage pollution generally results in a reduction in the predatory types and their replacement by scavengers. Regions of severe oxygen depletion may be devoid of fish, or inhabited only by rough fish such as gar or carp. The general concept of a reduction of variety coupled with an increase in abundance in certain regions is as valid for fishes as for other groups.

B Population responses to toxic pollution are unpredictable except that reduction in variety is again almost sure to result.

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CRITICAL PROBLEMS IN SYSTEMATICS

I FROM MONAD TO MAN

A Man's desire to classify has always been strong. Consequently this area received the early attention of philosophers and theologians.

B Classification and taxonomy provided a foundation and stimulus for biology. Some areas of biology were virtually dominated as systematics became a science in its own rights.

C Definition of terms

Systematics: "The scientific study of the kinds of diversity of organisms and of any and all relationships among them."

Classification: "The ordering of organisms into groups (or sets) on the basis of their relationships; that is, of their associations by contiguity, similarity, or both."

Taxonomy: "The theoretical study of classification, including its bases, principles, procedures, and rules."

Identification: "The use of a Key (or key substitute like an expert) to place an unknown organism into a specific taxonomic rank."

II CHANGING CONCEPTS IN SYSTEMATICS

A The basic foundations were laid by John Ray in the 17th century.

B In the 18th century, Linnaeus established the system of natural classification and binominal nomenclature in use today. His system utilized much of Ray's work. Basic categories added since Linnaeus are the family and phylum. His Systema Naturae (10th ed. 1758) is designated as the official beginning point for nomenclature.

C Historically, concepts in systematics are three-phased.

1 Alpha - Descriptive

2 Beta - Relationships

3 Gamma - New Syntheses and Future Systems

III THE SPECIES PROBLEM

A Necessity of identifying species

Studies of the ecology of any habitat require the identification of the organisms found in it. One cannot come up with definitive evaluations of stress on the biota of a system unless we can say what species constitute the biota. Species vary in their responses to the impact of the environment.

B Solutions to the problem

1 Evasion

Treat the ecosystem as a "black box"--a unit--while ignoring the constitution of the system. This may produce some broad generalizations and will certainly yield more questions than answers.

2 Compromise

Work only with those taxonomic categories with which one has the competence to deal. Describe the biotic component as a taxocenosis limited to one or two numerically dominant taxonomic categories, bearing in mind that numerically taxa which are ignored may be very important to the ecology of the ecosystem.

3 Comprehensive description

Attempt a comprehensive description of the biota. No one can claim competence to deal with more than one or two groups. The cooperation of experts must be obtained. The Smithsonian Institution has a clearinghouse for this sort of thing.[1] Lists of expert taxonomists can be obtained (2a, b, c)(3). There will be none for some groups. Also collaboration is time consuming.

IV PROBLEMS IN SYSTEMATICS

A A critical problem in classification has been the arbitrary assignment of characters for definition and separation of characters for definition and separation of taxa. Specialists in a limited taxonomic plant or animal group may sharply disagree over which values should be employed.

The subjective nature of this approach to systematics has not always been recognized.

B Specialists working with restricted plant or animal groups may be unable to communicate with specialists in other areas due to terminology used.

C As a result of the subjective element, the pendulum has swung between the "lumpers" and "splitters."

1 Lumpers is a term used loosely to describe systematists that deemphasize minute variations in populations of individuals. The snail species Pleurocera canaliculata has upstream and downstream forms (shell types). The lumpers insist that a great number of these forms are only varieties or ecotypes of a single highly variable species.

2 Splitters conversely describe those systematists that see minor variations as valid grounds for species separation. The splitters would recognize as a species each shell type, however minor.

V SYSTEMATICS AND AQUATIC BIOLOGY

A How far does the aquatic biologist go in systematics?

1 The aquatic biologist may or may not be a systematist or specialist in a limited taxon.

2 Some aquatic biologists have specialized in a particular taxon with good results.

3 Granted a fine degree of competence in one taxon, he will probably have only limited acquaintance with other taxa.

4 It should be obvious that no one can specialize in more than several taxa.

B The Non-Biologist Should:

1 Be acquainted with the basic biological system of natural classification and some basic terminology.

2 Realize the limitations of both systematics and the aquatic biologist handling systematics.

3 Understand that adequate and usable taxonomic treatment of all plant and animal groups proceeds at varying rates. Many groups (example: midges) are still in the Alpha phase.

C Facing Problems with the Systematic Literature

1 Identification of aquatic organisms is complicated by:

a Keys may be available for only one of the life history stages.

b Reproductive phases or type of egg deposition may be involved in correct identification.

c Seasonal changes in the organism may frustrate identification.

2 The literature is difficult to retrieve.

D How important is the correct identification to species with an aquatic organism? For example:

1 A test organism in a bioassay procedure

2 The sludgeworms in a bank of sludge below gross organic pollution

E Current Problems in Identification

1 Fewer students going into systematics

2 The marked reduction in our native flora and fauna due to man's activities. Many endemic "species" and groups (especially molluscs) have been extirpated.

3 Trend toward "lumping" in recent monographs

4 New syntheses in systematics

5 Numerical taxonomy

6 Stereo scanning and conventional electron microscopy

VI THE NEW SYSTEMATICS - FROM ART TO SCIENCE

A The new systematics, including the tool of numerical taxonomy, is constructed upon the old but seeks to create new syntheses along with increasing utilization of computer techniques.

B One element it seeks to displace is the subjective, which has made taxonomy more of an art than a science.

C Systematic Relationships are Recognized

1 Phenetic - based on overall similarities

2 Cladistic - based on common lines of descent

3 Chronistic - based on time relation among evolutionary branches

VII CONCLUSIONS

A Numerical taxonomy is gaining in techniques and application.

B There will be new syntheses in the field of systematics.

C The applications of computer classification and identification in the field of aquatic biology are unlimited.

* ACKNOWLEDGEMENT

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* Certain portions of this outline contain material from a prior outline by Dr. Henry Kritzler, Professor of Biological Oceanography, Florida State University.

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THE SYSTEM OF BIOLOGICAL CLASSIFICATION

I INTRODUCTION

There are few major groups of organisms that are either exclusively terrestrial or generally aquatic. The following remarks apply to both, however, primary attention will be directed to aquatic types.

II CLASSIFICATION

One of the first questions usually posed about an organism seen for the first time is: "what is it?" usually meaning, "what is its name?" The naming or classification of biological organisms is a science in itself (taxonomy). Some of the principles involved need to be understood by anyone working with organisms however.

A Names are the "key number", "code designation", or "file references" which we must have to find information about an unknown organism.

B Why are they so long and why must they be in Latin and Greek? File references in large systems have to be long in order to designate the many divisions and subdivisions. There are over a million and a half items (or species) included in the system of biological nomenclature (very few libraries have as many as a million books to classify).

C Common names are rarely available for most invertebrates and algae. Exceptions to this are common among the molluscs, many of which have common names which are fairly standard for the same species throughout its range. This may be due to their status as a commercial harvest or to the activities of devoted groups of amateur collectors. Certain scientific societies have also assigned "official" common names to particular species; for example, aquatic weeds - American Weed Society; fish - American Fisheries Society; amphibians (salamanders and frogs) - American Society of Ichthyologists and Herpetologists.

D The system of biological nomenclature is regulated by international congresses.

1 It is based on a system of groups and super groups, of which the foundation (which actually exists in nature) is the species.

2 The taxa (categories) employed are as follows:

The species is the foundation (plural: species)

Similar species are grouped into genera (singular: genus).

Similar genera are grouped into families.

Similar families are grouped into orders.

Similar orders are grouped into classes.

Similar classes are grouped into phyla (phylum).

Similar phyla are grouped into kingdoms.

Other categories such as sub-species, variety, strain, division, tribe, etc. are employed in special circumstances.

D The scientific name of an organism is its generic name plus its species name. This is analogous to our system of surnames (family names) and given names (Christian names).

1 The generic (genus) name is always capitalized and the species name written with a small letter. They

should also be underlined or printed in italics when used in a technical sense. For example:

Homo sapiens - (=sentiens) modern man

Homo heidelbergensis - heidelberg man

Homo neanderthalis - neanderthal man

Oncorhynchus gorbuscha - pink salmon

Oncorhynchus kisutch - coho salmon

Oncorhynchus tshawytscha - chinook salmon

2 Common names do not exist for most of the smaller and less familiar organisms. For example, if we wish to refer to members of the genus Gomphonema (a diatom) we must simply use the generic name, and:

Gomphonema olivaceum
Gomphonema parvulum
Gomphonema abbreviatum

three distinct species which have different significances to algologists interpreting water quality.

3 A complete list of the various categories to which an organism belongs is known as its "classification". For example, the classification of a type of diatom and a midge larva or "bloodworm" are shown side by side below. Their scientific names are Gomphonema olivaceum and Chironomus riparius.

a Examples of the Classification of an animal and a plant:

Kingdom	Plantae	Animalia
Phylum	Chrysophyta	Arthropoda
Class	Bacillariophyceae	Insecta
Order	Pennales	Diptera
Family	Gomphonemaceae	Chironomida
Genus	Gomphonema	Chironomus
Species	olivaceum	riparius

b These seven basic levels of organization are often not enough for the complete designation of one species among thousands; however, and so additional echelons of terms are provided by grouping the various categories into "super..." groups and subdividing them into "sub..." groups as:

Superorder, Order, Suborder, etc., Still other category names such as "tribe", "division","variety", "race", "section", etc., are used on occasion.

c Additional accuracy is gained by citing the name of the authority who first described a species (and the date) immediately following the species name. Authors are also often cited for genera or other groups.

d A more complete classification of the above midge, follows:

Kingdom Animalia

Superphylum Annelid

Phylum Arthropoda

Class Insecta

Order Diptera

Suborder Nematocera

Family Chironomidae

Subfamily Chironominae

Tribe Chironomini

Genus Chironomus

Species riparius Meigen 1804

e It should be emphasized that since all categories above the species level are essentially human concepts, there is often divergence of opinion in regard to how certain organisms should be grouped. Changes result as knowledge grows.

f The most appropriate or correct names too are subject to change. The species itself, however, as an entity in nature, is relatively timeless and so does not change to man's eye.

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THE CYCLING OF RADIONUCLIDES IN THE AQUATIC ENVIRONMENT

I INTRODUCTION

The desirability of plankton (tiny dispersed plants and animals) as objects of radiobiological investigation arises from a number of points:

A Their widespread occurrence in many kinds of aquatic habitats.

B Their ability to take up and to concentrate radionuclides, which may be injected, metabolized, and stored by higher organisms, including humans.

C Producing potential health hazards from ionizing radiations at the higher levels of concentration from radioactivity.

II PRELIMINARY DEFINITIONS AND CONCEPTS

A Radioecology of plankton and the food chain they begin requires a knowledge of physiology for the metabolic activities involved in the uptake of radioactive isotopes, as well as certain physical laws for the passive (dead) uptake of radionuclides, i.e., diffusion, imbibition.

B Some isotopes may be passively and instantaneously absorbed on the surface of the cells and are not taken into the cells. Cells of *Carteria* remove yttrium from the aquatic environment by adsorption on the surface, while the same cells take calcium and a similar substance strontium into the cells by absorption. These cells cannot, however, substitute strontium for calcium in their metabolism, because cells without calcium do not divide.

C In some cases, the concentration ratio will vary directly with the concentration of the isotope in the water, this being a linear function. In other cases, the isotope will be concentrated only to the extent that it is used. In still other cases, as phosphorus metabolism, the element may be concentrated considerably out of proportion to the available phosphorus in the aquatic environment.

D The concentration factor is the ratio of the activity of the wet weight of washed algal cells (disintegrations per minute, per gram) to the activity of the aquatic solution in which the organism was living (disintegrations per minute, per milliliter). By using concentration factors, planktonic algae may be compared for ability to concentrate radionuclides.

E A succession of organisms, beginning with those having photosynthesis (producers), and proceeding to herbivorous, omnivorous, and carnivorous organisms (consumers), each serving as a sustenance for the next, is called a food chain or cycle. Types of organisms are found at the bottom, middle, and the top of each of these chains.

III Phytoplankton (algae) take up and concentrate many kinds of isotopes, both stable and radioactive. The amount taken up of each isotope may vary with the age of the cells, the concentration of the dissolved or ionized isotope, and the pH. A rise in temperature may increase the diffusion, but could slow down the metabolism, which in turn would tend to decrease the active (respiratory) uptake of the isotope.

A Algae are noted for their ability to take up and to concentrate certain dissolved minerals from great dilutions in their environment.

1 Concentration of "essential" minerals (macronutrients), i.e., "C HOPKINS CaFe Mg NaCl."

2 Concentration of trace minerals (micronutrients) such as Cu, B, Mn, Zn, and Mo.

3 Accumulation of nonmetabolic substances

B Because of their minute sizes, phytoplankton present a great deal of surface for exchange with ions and substances in solution in water.

1 At times, algae occur in massive quantities (blooms). Under these conditions, they may selectively exhaust (take up) dissolved substances (phosphates, nitrates, and carbonates).

2 From inorganic substances are synthesized organic substances which become assimilated as protoplasm, or nonliving cell walls, etc.

3 Because they selectively take some substances out of solution, plankton have been used to decontaminate a water supply of known unwanted dissolved substances, or to reclaim valuable dissolved minerals.

4 Algae frequently concentrate substances without any known role to metabolism, i.e., cesium, rubidium, iodine, bromine, strontium, and yttrium.

IV Plants with photosynthesis are at the base (beginning) of the food chain for all aquatic life.

A In photosynthesis, plankton use radiant energy, CO_2, and H_2O to begin the elaboration of many complex organic compounds which are present in the web of aquatic life (biosphere). Radionuclides tied to these organic compounds may accumulate to concentrations dangerous to metabolism all along the food chain, depending on the selective habits of the herbivorous and predaceous animals. A "hot" fish may be radioactive from having fed on caddis fly larvae, which in turn fed on "hot" algae. The relative position in the food pyramid determined the concentration of the radioisotope.

B During periods of elaboration of large planktonic populations (blooms) peaks of radioactivity will occur near the surface with the algae. Consequently, this radioactivity may be manifested as a surface phenomenon moving down stream; however, in bodies of water with little or no current (lakes and ponds), the radioactivity may be concentrated with the algal blooms, in a stationary position.

C On degradation of the dead algal cells, the detritus formed from the algae may carry some of the radioactivity to the bottom in the form of silt making "hot" conditions for bottom-dwelling organisms.

D In a flowing stream, the specific activity will diminish along the food chain.

V METHODS OF COLLECTING INFORMATION ABOUT POSSIBLE RADIOACTIVITY OF PLANKTON AND THE FOOD CHAINS THEY COMMENCE

A Take a sample of plankton from the stream and measure its radioactivity.

B Control culture the plankton with the medium dosed with known concentrations of radioisotopes, so as to calculate the concentration factors for each radionuclide.

C Add plankton-feeding animals to an aquarium containing "hot" algae to measure the amount of radioactive uptake from the feeding of the animals on the plankton.

D Vary pH, temperature, time of exposure, age of culture and cells and note large changes in the concentration factor.

VI SOURCES OF RADIONUCLIDES

A Naturally Occurring

1 In soils, rock, etc. (uranium, radium)

2 In biota--mostly K^{40}

B Nuclear Testing

1 Air

2 Ground

3 Water and,

4 Beneath ground

C Thermonuclear Wars

D Disposal of Radionuclides

1 From power reactors

Activation of material exposed to neutron flux. Fission products

2 From widespread use of radioactive isotopes in medicine and industry

3 Nuclear powered submarines, surface ships and aircraft

4 Burial

In the oceans; in abandoned salt mines, etc., in space

VII RELATIVE DISTRIBUTION OF RADIONUCLIDES IN AQUATIC ENVIRONMENTS

A Water

B Sediment

C Biota

VIII METHODS OF BIOLOGICAL CYCLING OR RADIONUCLIDES

A Uptake and Retention

1 Active (metabolic)

2 Passive (adsorption) and simple diffusion

IX METHODS OF QUALITATING AND QUANTITATING RADIONUCLIDES FROM AQUATIC HABITATS

X CONCLUSIONS

A Food Chains

B Chemical, Physical and Biological Factors

C Need for Continuous Monitoring

D Use of Indicator Tissues and Organisms for Specific Radionuclides in Food Chains

TABLE I. UPTAKE OF CESIUM^{137} BY SPECIES OF ALGAE

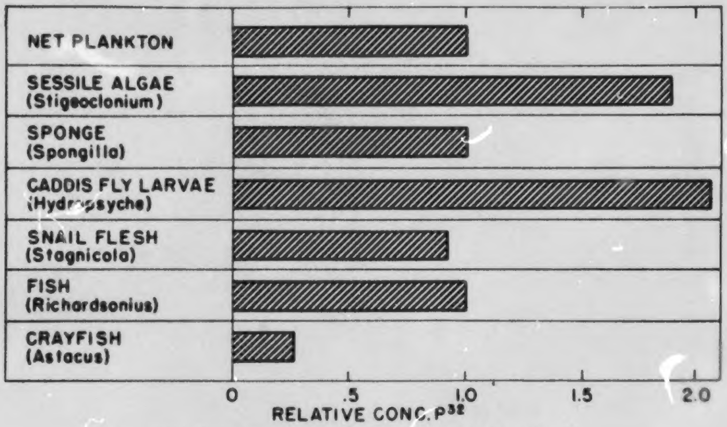
Species	ppm of k	Days after Dosing	Concentration Factors
Rhizoclonium hieroglyphicum	1	5	1530
Oedogonium vulgare	1	3	790
Spirogyra ellipsospora	1	2	341
Spirogyra communis	13	5	220
Gonium pectorale	10	2	138
Oocystis elliptica	10	10	670
Chlamydomonas sp.	8	5	52
Euglena intermedia	8	14	706
Chlorella pyrenoidosa	8	11	154
Uptake by dead (formalin-killed) cells:			
Chlorella pyrenoidosa	0.3	3	96
Euglena intermedia	0.3	3	16

TABLE II. CONCENTRATION OF CESIUM^{137} IN EUGENA

CELLS/ml		CONCENTRATION FACTORS		
BEGINNING	AT 40 HRS.	18 HRS.	40 HRS.	96 HRS.
144,000	146,100	3.4	8.2	62
86,000	113,800	3.4	11.3	58
36,000	60,000	4.6	15.4	28
21,000	68,300	5.9	17.0	26
18,000	55,500	6.4	19.4	19
1,400	27,700	5.3	11.0	16

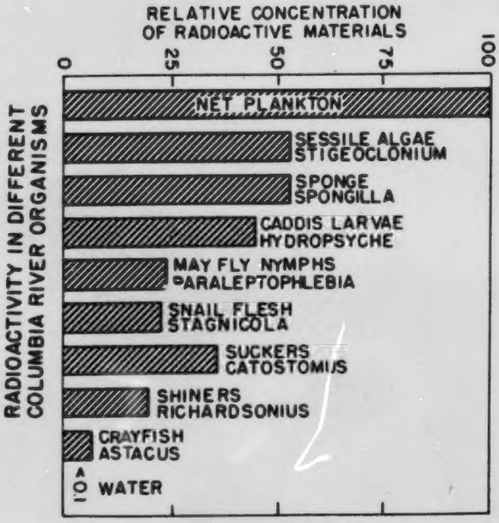
"L. G. Williams"

FIGURE 1



RELATIVE CONCENTRATION OF P^{32} IN COLUMBIA RIVER ORGANISMS

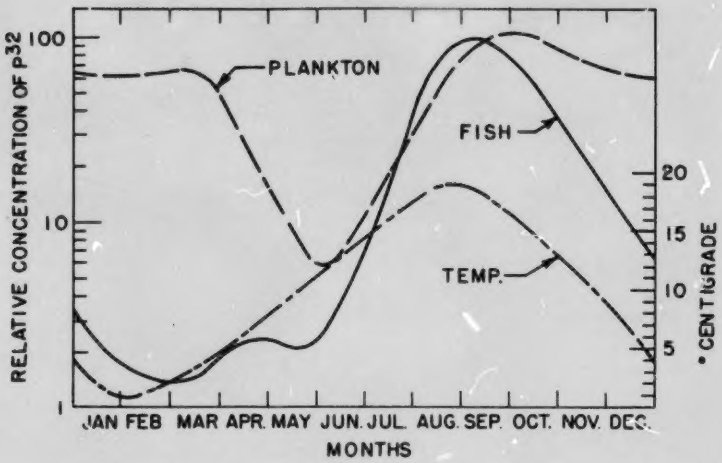
FIGURE 2



Davis and Foster, "Bioaccumulation of Radioisotopes through Aquatic Food Chains," Ecology 39: 530-535, 1958.

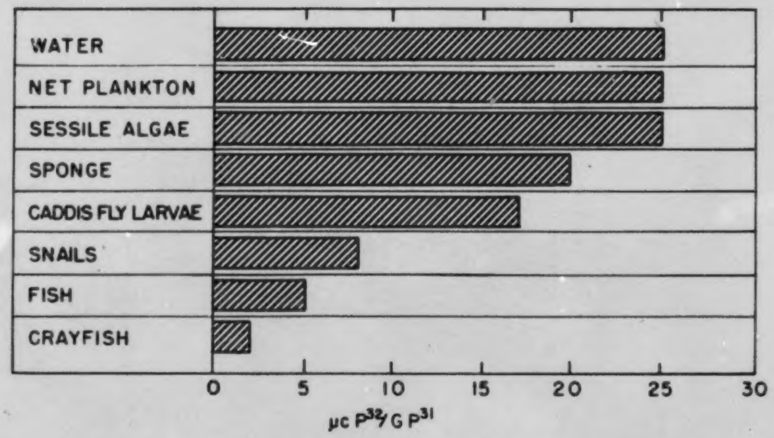
"R. F. Foster"

FIGURE 3

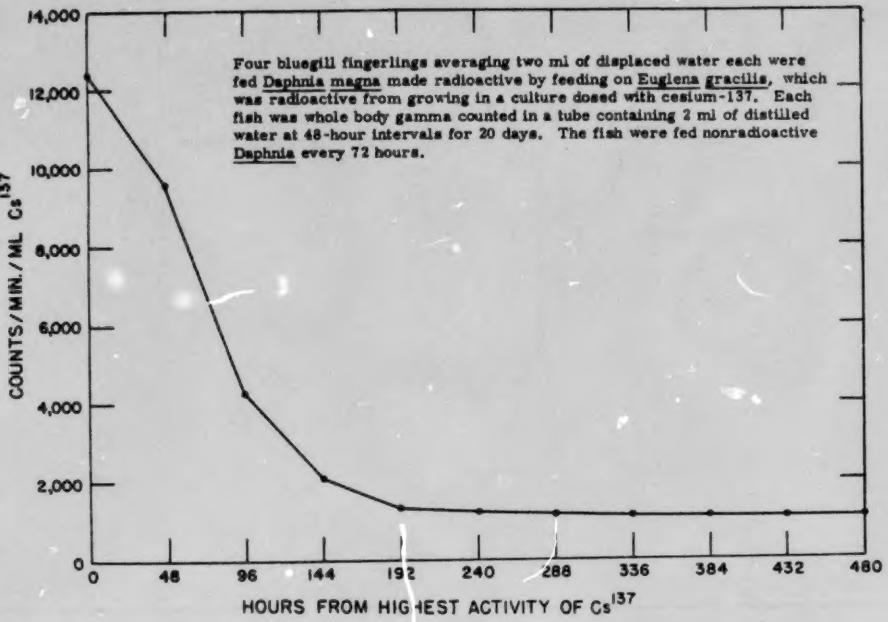


SEASONAL VARIATIONS IN THE CONCENTRATION OF P^{32} IN COLUMBIA RIVER PLANKTON AND FISH

FIGURE 4

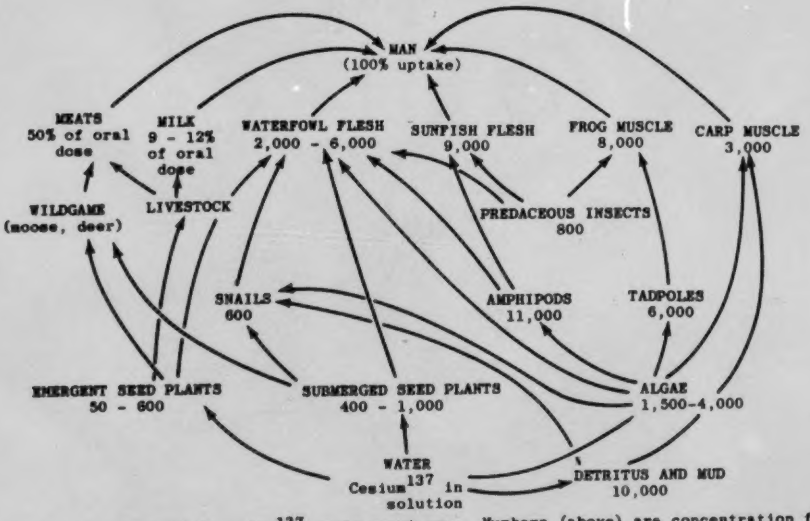


SPECIFIC ACTIVITY OF COLUMBIA RIVER ORGANISMS



Four bluegill fingerlings averaging two ml of displaced water each were fed Daphnia magna made radioactive by feeding on Euglena gracilis, which was radioactive from growing in a culture dosed with cesium-137. Each fish was whole body gamma counted in a tube containing 2 ml of distilled water at 48-hour intervals for 20 days. The fish were fed nonradioactive Daphnia every 72 hours.

FIGURE 5



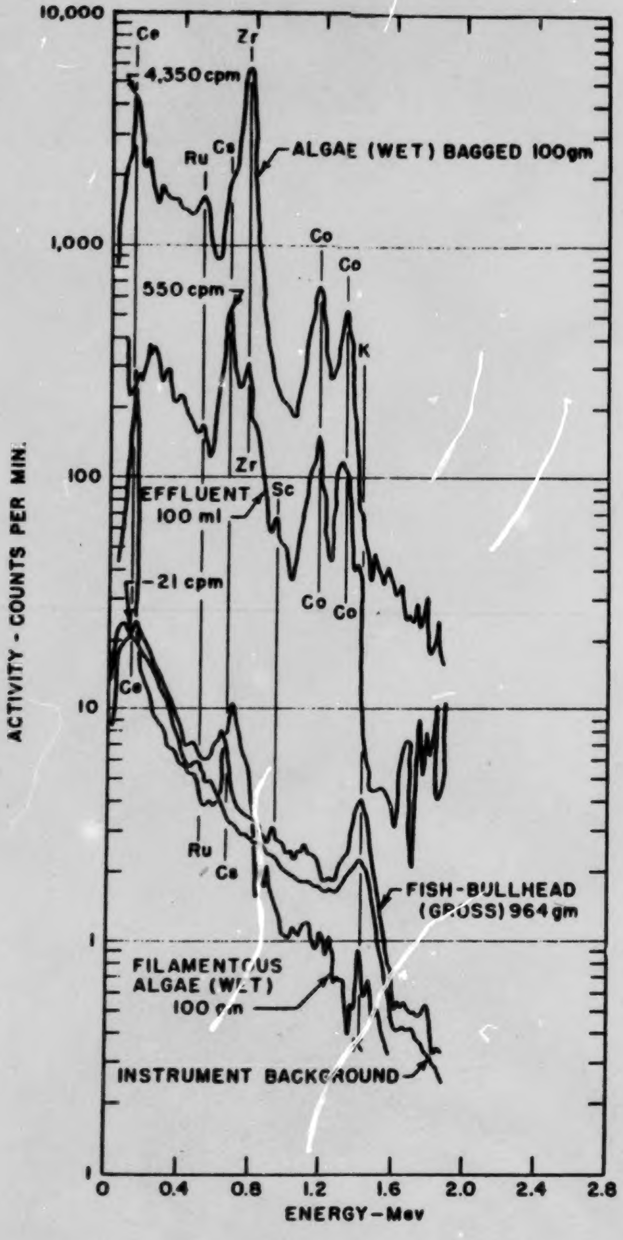
MAN
(100% uptake)
MEATS
50% of oral
dose
MILK
9 - 12%
of oral
dose
WATERFOWL FLESH
2,000 - 6,000
SUNFISH FLESH
9,000
FROG MUSCLE
8,000
CARP MUSCLE
3,000
WILDGAME
(moose, deer)
LIVESTOCK
PREDACEOUS INSECTS
800
SNAILS
600
AMPHIPODS
11,000
TADPOLES
6,000
EMERGENT SEED PLANTS
50 - 600
SUBMERGED SEED PLANTS
400 - 1,000
ALGAE
1,500-4,000
WATER
$Cesium^{137}$ in
solution
DETRITUS AND MUD
10,000

Food web through which $cesium^{137}$ could reach man. Numbers (above) are concentration factors.

$$\text{Concentration factors: } \frac{Cs^{137}\text{ concentration in organism}}{Cs^{137}\text{ concentration in water}}$$

"L. G. Williams, 1960"

FIGURE 7



Uptake of radionuclides from the Mohawk River, New York, at 17°C. in September, 1959, after 72 hours by Pithophora in perforated polyethylene bags, compared with activity of fish (bullhead) and an indigenous filamentous green alga, Cladophora, taken from the river. Uptake of these radionuclides by Pithophora was nonmetabolic, since the alga had been killed with chlorine.

"L. G. Williams"

FIGURE 8

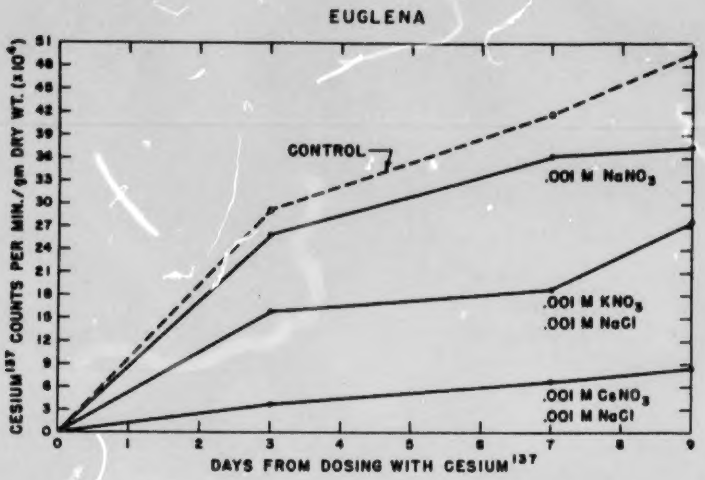
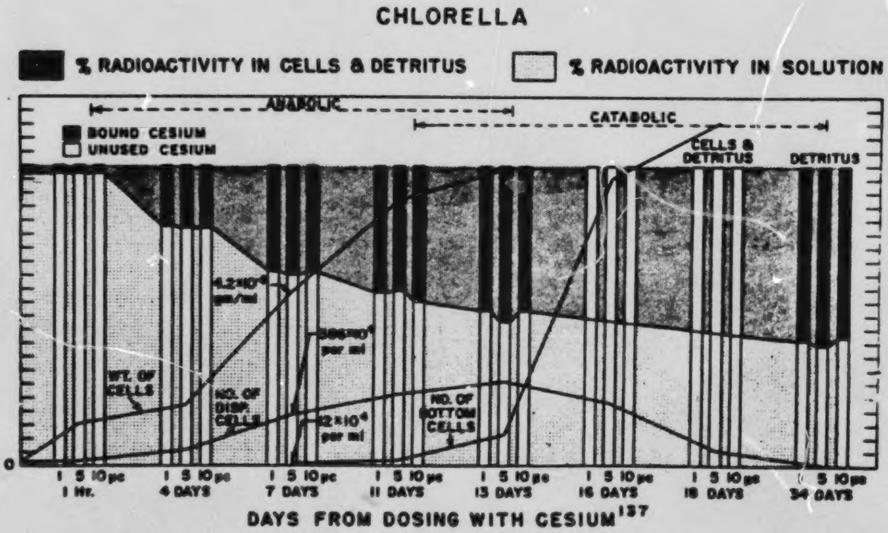

EUGLENA

FIGURE 9


CHLORELLA

"L. G. Williams"

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PROCEDURES FOR FISH KILL INVESTIGATIONS

I INTRODUCTION

Fish kills in natural waters, though unfortunate, can in many instances indicate poor water quality leading to investigations which may improve water quality. Prompt investigations should be organized and conducted so that the resultant data implicates the correct cause. Fish kills tend to be highly controversial, usually involving the general public as well as a number of agencies. Therefore, the investigator can expect his findings to be disputed, quite possibly in a court of law.

The following procedures are presented as a working guide for investigating and reporting fish kills as developed by the personnel of The Lower Mississippi River Comprehensive Project (FWPCA).

II TYPES AND EXTENT OF FISH KILLS

A Natural Mortalities - Those which are caused through natural phenomena such as; acute temperature change, storms, ice and snow cover, decomposition of natural materials, salinity change, spawning mortalities, parasites, and bacterial or viral epidemics.

B Man caused fish kills - Produced by environmental changes through man's activity, and may be attributed to municipal wastes, industrial wastes, agricultural activities and water control activities.

C One dead fish in a stream may be called a fish kill; however, in a practical sense some minimal range in number of dead fish observed plus additional qualifications should be used in reporting and classifying fish kill investigations. The following definitions should be used as guidelines in reporting fish kill investigations. These qualifications are based on a stream approximating 200 feet in width and 6 feet in depth. For other size streams, adjustments should be made.

1 Minor fish kill considered here as NO fish kill and reported so: 1 - 100 dead or dying fish confined to a small area or stream stretch. Providing this is not a reoccurring or periodic situation. For example, near a waste outfall in which stream dilution plays its part and nullifies the effect of the deleterious material. If this is a reoccurring situation, it could be of major significance and, therefore, investigated.

2 Moderate fish kill: 100 - 1000 dead or dying fish observed. In a stream where dilution has had the chance to play its role involving a mile or so of stream, a number of species are affected; and apparently normal fish can be collected immediately downstream from the observed kill area.

3 Heavy fish kill: 10,000 fish or more observed dead or dying. In a stream where dilution has had the chance to play its part, but ten miles or more of the stream are involved, many species of fish are affected and dying fish may still be observed downstream.

III PREPARATION FOR FIELD INVESTIGATION

A Secure maps of area to be investigated.

1 U.S. Geological Survey maps

a 1/250,000 scale for general location

b 1/24,000 for accurately defining the kill area in the field

2 Navigation maps (appropriate agency)

3 Other sources

4 From the data received from the reporting agency, locate the kill area on the map.

a Determine best access points.

b Locate possible known industries, municipalities, or other potential sources of pollution.

c Estimate the possible area to be traveled or inspected on

1) water

2) land

3) both

B Secure sampling equipment and determine size of investigation team needed.

1 Standard equipment to be taken on all investigations (a standard checklist with space for special equipment will often save embarrassment in the field.)

a Thermometer

b Dissolved oxygen sampler

c D.O. bottles

d Winkler D.O. test kit

e Conductivity test meter

f pH test meter or chemical kit

g Sample bottles

h Pencils and note paper

i Current edition of "Standard Methods for the Examination of Water and Wastewater "

2 If preliminary information is available on the possible cause of the kill, consult the latest edition of "Standard Methods" for specific physical and chemical equipment required for collecting, analyzing, or preserving samples possibly containing the suspected causative agent.

3 Form an investigating party

a If only one man is available to make the investigation, preference for choosing the man should be in this order

1) Specialized professional personnel, such as, engineer, chemist, or biologist who is experienced in investigating fish kills and who is capable of adequately reporting the technical aspects of the investigation.

2) A non-specialized professional engineer, chemist, or biologist who has little or no experience in fish kill investigations, but who is capable of adequately reporting the technical aspects of the investigation.

3) A technician who has considerable field experience in pollution and fish kill investigations and who is capable of reporting some of the technical aspects of the investigation.

4) An office technician or other personnel who has had limited field work in pollution investigations.

b If two or more men are needed for the investigation, the party should include at least one person under category (1) above. Preferably, the team should include:

1) A biologist to make a survey of the biological changes.

2) An engineer to make an evaluation of the physical condition of the fish kill area and to make an investigation of an industry or a municipal wastewater treatment plant if needed.

c If a fish kill is observed in its initial state in the field by any one of the people listed under the classification in Section B.3.a., the project office should be informed immediately (after working hours the project director or deputy director should be informed) so that an adequately equipped, specialized investigating party can be formed if needed.

C Contact personnel of the laboratory or laboratories which will participate in analyzing samples. If possible estimate the following and record on sample form No. 1.

1 The number and size of samples to be submitted

2 The probable number and types of analyses required

3 The dates the samples will be received by the laboratory

4 Method of shipment to the laboratory

5 To whom the laboratory results are to be reported

6 The date the results are needed

IV MAKING THE FIELD INVESTIGATION

A Contact the local lay person or official who first observed the kill and reported it.

1 Obtain any additional information which might be helpful which was not reported previously.

2 If possible, retain the reporting party as a guide or invite him to accompany the investigating team.

B Make a reconnaissance of the kill area.

1 Make a decision as to the extent of the kill and if a legitimate kill really has occurred.

2 If a legitimate kill exists take steps to trace or determine the cause.

a Always perform the following physical or chemical tests, during the initial steps of the investigation:

1) Temperature

2) pH

3) Dissolved oxygen

4) Specific conductance

While none of these factors may be directly involved in the kill these tests are performed simply and rapidly in the field and can be used as a baseline or starting point for isolating the cause (s) of the kill.

b Record other physical observations such as:

1) Appearance of water, i.e., turbidity, high algal blooms, oily, unusual appearance, etc.

2) Stream flow pattern, i.e., high or low flow, stagnant or rapidly moving water, tide moving in or out, etc. If possible obtain reading from stream gage if one is near kill area.

3) Weather conditions prevailing at the time of the investigation and information on weather immediately prior to the kill

3 Make a rough sketch or define the kill area on a map so that sampling points, sewer outfalls, etc. can be accurately located on a drawing to be included in a final report.

4 Take close-up and distance photographs of:

a Dead fish in the stream in the polluted area.

b The stream above the polluted area.

c Wastewater discharges.

Photographs will often show a marked delineation between the wastewater discharge and the natural flow of water. Pictures taken at a relatively high elevation, (a bridge as opposed to a boat or from a low river bank) will show more and be more effective. Color photographs are also more effective in showing physical conditions of a stream in comparison to black and white prints.

C Sampling Procedures - The extent and method of sampling will depend upon location and upon the suspected cause of the kill.

1 Stream and wastewater sampling.

a Sample the following points when the pollutional discharge is coming from a well defined outfall.

1) The effluent discharge outfall

2) The stream at the closest point above the outfall which is not influenced by the waste discharge

3) The stream immediately below the outfall

4) Other points downstream needed to trace the extent of the pollution

b The sampling should be extensive enough that when all the data is compiled no question will exist as to the source of the pollution which killed the fish.

c The number of samples to be collected at a given cross section will depend principally on the size of the stream.

1) Streams less than 200 feet wide, not in an industrial area usually can be adequately sampled at one point in a section (Figure 1).

2) Streams 200 feet or wider generally should be sampled two or more places in a section immediately above and below the pollutional discharge; where the pollutional waste has adequately mixed with the stream flow one sample may suffice.

3) A number of samples in a cross section may be required on any size of stream to show that the suspected pollutional discharge is coming from a source located in an industrial or municipal complex (Figure 2).

4) Extensive cross sectional sampling on rivers greater than 200 feet wide will be required for kills involving suspected agricultural or other types of mass runoff.

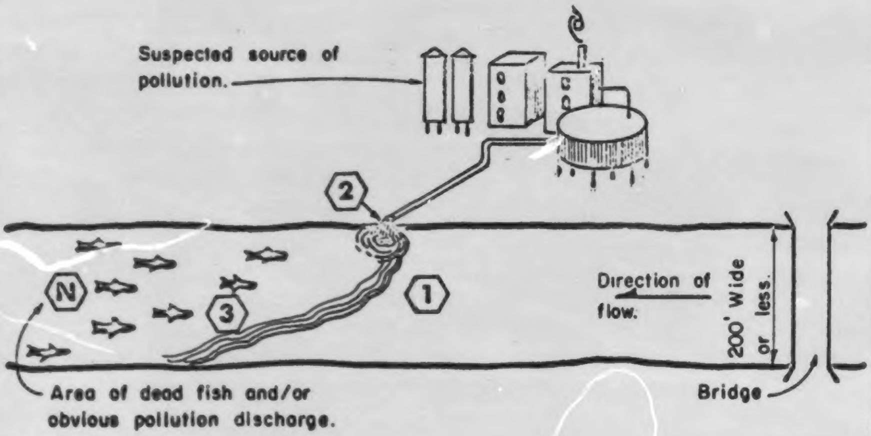
Suspected source of pollution.
2
N
3
1
Direction of flow.
200' Wide or less.
Area of dead fish and/or obvious pollution discharge.
Bridge

Figure I — Minimum Water Sampling Point On Stream 200 Feet Or Less Wide Involving An Isolated Discharge.

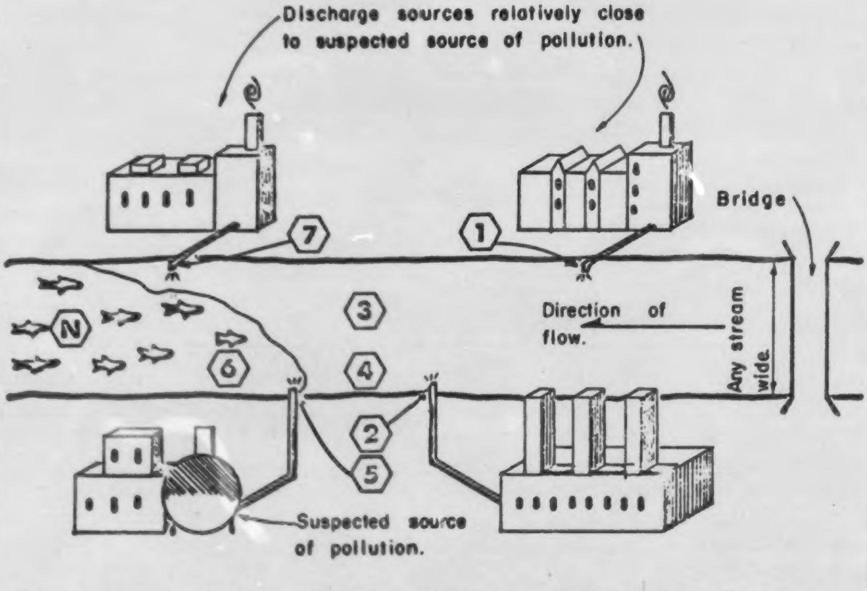
Discharge sources relatively close to suspected source of pollution.
Bridge
7
1
N
3
Direction of flow.
Any stream wide.
6
4
2
5
Suspected source of pollution.

Figure 2 — Minimum Water Sampling Points On A Stream Running Through An Industrial Or Municipal Complex.

PLATE I - RELATIONSHIP OF FISH KILLS TO SOURCE OF TOXICITY

5) Sample depths - On streams 5 feet in depth or less, one mid-depth sample per sampling locations. For streams of greater depths, appropriate sampling judgment should be used, since stratification may be present.

Explanation of Plate I

1) Collection point 1, Figure 1 and points 3 and 4, Figure 2 should be collected as near to the point of pollutional discharge as possible. These points will vary according to stream flow conditions; the pollutional discharges into a slow sluggish stream usually will have a cone of influence upstream of the outfall; whereas, a swift flowing stream usually will not.

2) Collecting an upstream control sample from a bridge within sight of the pollutional discharge would probably be satisfactory in Figure 1 but definitely not in Figure 2.

3) Figures 1 and 2 are given for illustrative purposes only and should be used only as a guide for sampling. Thought must be given to each individual situation to insure adequate, proper sampling. While too many samples are better than too few, effort should be made not to unduly overload the laboratory with samples collected as a result of poor sampling procedures.

2 Biological sampling

a In every investigation of fish or wildlife kills the paramount item should be the immediate collection of the dying or only recently dead organism. This may be done by anyone, sampling and preservation is as follows:

1) Collect 20 plus drops of blood in a solvent rinsed vial, seal same with aluminum foil, cap and freeze.

2) Place bled carcass, or entire carcass if beyond bleeding stage, in plastic bag and freeze. In case no method of freezing is available, icing for a short period prior to freezing may be acceptable. Labeling of both blood and carcass is important.

3) Controls - live specimens of the affected organisms should be obtained from an area within the same body of water which had not been influenced by the causative agent. Once obtained these specimens should be handled in a like manner.

b The number of individuals involved and the species affected should be enumerated in some manner. At most these will be estimates. Depending on the given situation such as area or distance involved and personnel available enumeration of fish kills may be approached in one of the following ways.

1) For large rivers, establish observers at a station or stations (e.g., bridges) and count the dead and/or dying fish for a specified period of time, then project same to total time involved.

2) For large rivers and lakes, traverse a measured distance of shoreline, count the number and kinds of dead or dying fish. Project same relative to total distance of kill.

3) For lakes and large ponds, count the number and species within measured areas, and then project to total area involved.

4) For smaller streams one may walk the entire stretch involved and count observed number of dead individuals by species.

3 Biological sampling Macro-Invertebrates:

a Sampling of benthic organisms after the more urgent aspects of the kill investigation has been completed can prove to be rewarding relative to extent and cause of kill. Since this general form of aquatic life is somewhat sedentary by nature any release of deleterious materials to their environment will take its toll. Thus by making a series of collections up and downstream, the affected stretch of stream may be delineated when the benthic populations are compared to those from the control area. Also the causative agent may be realized when the specifics of the benthic population present are analyzed.

b Other aspects of the biota which should be considered are the aquatic plants. In lakes and ponds floating and rooted plants should be enumerated and identified. The collection of plankton (rivers and lakes) should be taken in order to determine the degree of bloom, which in itself may cause fish kills because of diurnal DO levels.

c Both aquatic plants and macroinvertebrates may be preserved in a 5% formalin solution.

4 Bioassay

Static bioassay techniques as outlined in Standard Methods may be effectively used to determine acute toxicity of wastes as well as receiving waters.

a In situ using live boxes

b Mobile bioassay laboratory

c Samples returned to Central Lab for toxicity tests

V DETAILED EXAMINATION OF SOURCE OF POLLUTION

A Seven general categories under which causes of kills can be grouped are:

1 Industrial waste discharges

2 Waste discharges from municipal sewerage systems

3 Water treatment plant discharges

4 Agriculture and related activities

5 Temporary activities

6 Accidental spills of oil and other hazardous substances

7 Natural causes

B Industrial Waste Discharges

1 Upon locating the outfall source, collect a sample immediately if possible at the point where the wastes leave the company property.

2 Make an in-plant inspection if possible.

a Contact the plant manager or person in charge.

b Request a brief tour of the facilities.

c Obtain general information concerning the products manufactured; raw materials; manufacturing process; quantities, sources, and characteristics of wastes; and waste treatment facilities if any. Possibly the company may be able to supply a flow diagram or brochure of the plant operations.

d Request specific information concerning the plant operation immediately prior to the start of the kill.

C Waste discharges from a municipal or domestic type sewerage system

1 Discharges from this source may be domestic sewage and industrial wastes combined with domestic sewage. These wastes may be subjected to treatment of a municipal treatment plant or may be discharged directly, untreated to a stream.

2 Generally, the municipality or owner of the sewerage system is held responsible for any discharge in such a system; consequently, after collecting samples, the owner or a representative of the owner of the sewerage system should be contacted. This may be a sewage treatment plant operator, city engineer, public works supervisor, a subdivision developer, etc.

a Obtain information about the operation of the system.

b If the cause of the kill was the result of an industrial waste discharge to a municipal sewer and thence to a stream, information should be obtained from a municipal official about the industry and the problem. An inspection of the industrial plant may be desirable. Generally, this should be done only in cooperation with a municipal official.

D Agriculture and Related Activities

1 Pollution capable of causing fish kills may result from such agricultural operations as crop dusting and spraying fertilizer applications, and manure or other organic material discharges to a stream.

2 Generally, kills related to these factors will be associated with high rains and runoff.

3 The source or type of pollution may be difficult or impossible to locate exactly. It may involve a large area. Talking to local residents may help pinpoint the specific problem area. Runoff from fields, drainage ditches, and small streams leading to the kill area are possible sampling places which may be used to trace the cause.

E Temporary Activities

1 Causes of kills may result from such temporary or intermittent activities as mosquito spraying, construction activities involving chemicals, oils, or other toxic

substances, and weed spraying with herbicide containing materials toxic to fish such as arsenic.

2 As with agricultural activities, tracing the cause of these kills is difficult and may require extensive sampling.

3 Accidental spills from ruptured tank cars, pipelines, etc., and dike collapse of industrial ponds are frequently sources of fish kills.

F Possible Natural Causes of Fish Kills

1 Types of natural causes

a Oxygen depletion due to ice and snow cover on surface waters

b Oxygen depletion at night because of plant respiration or at anytime during the day because of natural occurring organics in the water

c Abrupt temperature changes

d Epidemic and endemic diseases, parasites, and other natural occurring biological causes

e Lake water inversion during vernal or autumnal turnover which results in toxic material or oxygen-free water being brought to the surface

f Interval seiche movement in which a toxic or low DO hypolimnion flows up into a bay or bayou for a limited period of time, and later returns to normal level

2 Fish kills in rivers below high dams immediately following the opening of a gate permitting hypolimnionic water to flow down the stream (as in TVA region)

VI CASE HISTORY

A The Lower Mississippi Endrin kill is an excellent example of the investigation of a major fish kill. Bartsch and Ingram give the following summary (See Table 1).

TABLE 1

ELEMENTS OF INVESTIGATIONS

I Examination of usual environmental factors

II Elimination of parasites, bacterial or viral diseases and botulism as causes of mortalities*

III Considerations of toxic substances: Examination and prognostication of symptoms of dying fish. Autopsy, including:

  Haematocrits and white cell counts

  Kidney tissue study

  Brain tissue assay for organic phosphorus insecticide

  Tissue analysis for 19 potentially toxic metals

  Gas chromatographic analysis of tissues, including blood, for chlorinated hydrocarbon insecticides

IV Explorations for toxic substances:

  Bioassay with Mississippi River water

  Bioassay with extracts from river bottom mud

  Bioassay with tissue extracts from fish dying in river water and bottom mud extracts

  Bioassay with endrin to compare symptoms and tissue extract analyses with those of dying fish in all bioassays

V Intensive chemical analysis for pesticides in the natural environment, experimental environment, river fish, and experimental animals

VI Surveillance of surface waters for geographic range and intensity of pesticide contamination

VII Correlation and interrelation of findings

---

* The investigator should be aware of the fact that apparently healthy fish may be harboring pathogenic bacteria in their bloodstreams (see Bullock and Snieszko). Thus there may be several factors involved in fish mortalities, all of which may obscure the primary cause or causes.

The investigation was designed to consider and eliminate potential fish kill possibilities that were not involved and come to a point focus on the real cause. It was found that the massive kills were not caused by disease, heavy metals, organic phosphorus compounds, lack of dissolved oxygen or unsuitable pH. Blood of dying river fish was found to have concentrations of endrin equal to or greater than laboratory fish killed with this pesticide, while living fish had lesser concentrations. Symptoms of both groups of dying fish were identical. It was concluded from all data obtained that these fish kills were caused by endrin poisoning.

B Recent investigations in Tennessee have shown that the leaking of small amounts of very toxic chemicals from spent pesticide-containing barrels used as floats for piers and diving rafts in lakes and reservoirs can produce extensive fish kills. The particular compound used to control slime growth in manufacturing processes, contained two primary chemicals in solution (phenylmercuric acetate and 2, 4, 6-trichlorophenol). The former compound which breaks down to form diphenylmercury was found to be more toxic to aquatic life than the latter.

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Project Personnel
Contacted:

a. Name ____________

b. Means of Contact ____________

c. Date & Time ____________

1. Reporting source

a. Agency ____________

(1) Address ____________

(2) Phone (s) ____________

b. Individual ____________

(1) Address ____________

(2) Phone ____________

(3) Fish Kill Network ______ yes ______ no

c. Other Contacts ____________

(1) Address ____________

(2) Phone ____________

(3) Fish Kill Network ______ yes ______ no

2. Data furnished by reporting source

a. Location of Kill ____________

b. Dates of Kill ____________ Dying last observed ____________

c. Kinds of organisms ____________

d. Approximate number killed ____________

e. Cause of kill (if known) ____________

f. Suspected causative sources ____________

g. Measures taken ____________

h. Other Agencies contacted ____________

(1) Date and Time ____________

3. Action requested

a. Field investigations ____________

b. Laboratory analysis ____________

4. Assistance to Project

a. Provided by ____________

b. Personnel ____________

c. Equipment ____________

d. Transportation facilities ____________

SPECIAL APPLICATIONS AND PROCEDURES FOR BIOASSAY

I INTRODUCTION

A The report of the Council on Environmental Quality (1970) repeatedly stresses the need for the development of predictive, simulative, and managerial capabilities to combat air and water pollution. The last capability depends on the first two.

B The standard static jar fish bioassay, which uses death as a response, enables one to predict the toxicity of a particular waste to fish. One limitation of this procedure is that it uses a grab sample which represents the quality of the waste at only one point in time. The water used to make the dilutions is also taken at one point in time. At the actual industrial site, the quality of the waste and the river water vary through time. A composite waste sample partially overcomes this limitation, but may mask variations that are biologically important.

C One could put fish in a continuous flow of waste diluted with river water, but then there is one further limitation of the standard bioassay: death is used as the response. In order to prevent damage to organisms, it is necessary to have an early warning of dangerous conditions, so that corrective action can be taken. In other words, symptoms of ill health, which occur before death, must be detected if there is to be time for diagnosis and treatment.

II METHODS AND MATERIALS

A Fish Movement Patterns

1 Fish movement patterns can be monitored using the technique of light beam interruption described in detail by Cairns, et al. (1970). Dawn and dusk are simulated by a motor-driven dimming unit which gradually increases the intensity of the room lights over a half-hour period starting at 6:30 a.m. and gradually decreases the intensity to 0 over a half-hour period starting at 6:30 p.m. The cumulative movement of each of six bluegill sunfish, a single fish per tank, is recorded every hour throughout a test except during the simulated sunrise and sunset when an additional record is made on the half hour. Each day is divided into four intervals; first half day, second half day, first half night and second half night (Table I). Before any statistical analysis can be performed, recordings for day 1 must be completed. After the cumulative movement for day 1 is recorded, statistical analyses are performed after the completion of each designated time interval. For example, the cumulative movement recorded hourly for each fish during day 1, first half day values are compared to the cumulative movement recorded hourly for each fish during day 2, first half day values.

2 Based on the results of 20 laboratory experiments "stress detection" is defined as the presence of two or more abnormal movement patterns recorded during the same time interval.

B Fish Breathing

1 Breathing rates may be determined from polygraph recordings of breathing signals. The fish are tested in plexiglas tubes through which dechlorinated tap water or some toxic solution is metered at a flow rate of approximately 100 ml/min. Breathing signals are detected by three platinum wire electrodes placed in the water; an active electrode, an indifferent electrode, and a ground. The test chambers and methods of acclimating the fish are described in more detail by Cairns, et al. (1970) The photoperiod is the same as that for the fish movement study.

2 The fish are placed in test chambers by 6:00 p.m. and the recordings began at 6:00 a.m. the next day to allow the fish to recover overnight from handling. Toxic solutions are introduced at 10:00 a.m. after the experimental fish have been exposed to water containing no added

toxicant for periods of one to six days. Each experimental fish thus serves as its own control. In addition, one or two fish are never exposed to the toxicant and serve as controls throughout each experiment. In one experiment, using zinc as the toxicant, reported in Table VI, six control fish were exposed to water containing no added zinc for four days.

a Preliminary exidence suggested that the data could be analyzed by separating the experimental day into four periods; a period from 6:00 to 8:00 a.m. when the breathing rates changed markedly, a period from 9:00 a.m. to 5:00 p.m. when the rates were comparatively high, another period of rapid change from 6:00 to 8:00 p.m., and a night period from 9:00 p.m. to 5:00 a.m. when the rates were comparatively low (Sparks, *et al.*, 1970).

b Bluegills increase their breathing rates when exposed to zinc (Cairns, *et al.*, 1970). An individual fish was thus considered to have shown a response each time its breathing rate during a time period exceeded the maximum breathing rate observed during the corresponding period of the first day, before any zinc was added. A response was scored for each value on the second day that was higher than the first day maximum for the comparable period. The control periods (before any zinc was added) and the experiment where no zinc was added at all were used to determine how many false detections this method of analysis would produce. The experimental periods (after zinc was added) determined how quickly the method of analysis could detect zinc concentrations in water.

c Zinc concentrations were determined daily by atomic absorption spectrophotometry.

III RESULTS

A Fish Movement Patterns

1 Table 1 shows the results of one continuous flow experiment carried out for 20 days. During this experiment fish were exposed to zinc on day 7 from 1:00 p.m. until 7:00 p.m. at which time the flow was returned to normal dilution water. The zinc concentrations reached their maximum at 7:00 p.m. and atomic absorption analyses on effluent samples collected at this time showed the following concentrations: tank one, 13.32; tank two, less than 0.08; tank three, 11.39; tank four, 12.72; tank five, 13.32; and tank six, 12.59 mg/l Zn^{++}. The results show that these concentrations of zinc developing over the six hour interval of exposure were insufficient to cause a detectable change in the movement patterns of the fish. By 8:30 a.m. of day 8 the effluent zinc concentrations were less than 0.30 in all cases.

2 To determine the percent survival and recovery patterns of the fish once stress detection occurred, zinc flow was reinitiated at 1:00 p.m. on day 13 of this experiment. Between 8:00 and 9:00 p.m. on day 13 the zinc concentration in the effluent reached a maximum of: 7.51 for tank one; less than 0.05 for tank two; 7.49 for tank three; 7.52 for tank four; 7.49 for tank five; and 7.54 mg/l for tank six. The concentrations remained near the above values until the statistical analyses showed "stress detection" during the first half night values on day 14 (Table 1). As soon as stress detection occurred the flow was returned to normal dilution water. At 10:00 a.m. on day 15 zinc analyses showed all effluent concentrations to be less than 0.70 mg/l Zn^{++}. Stress detection continued to be registered for two consecutive time intervals following the initial detection, but after that no stress detection was registered and the frequency of abnormal patterns returned to prestress levels within 48 hours. In this experiment

as with all others in which dilution water containing zinc was replaced with dilution water minus zinc at that time of stress detection all fish survived!

3 The results from the series of experiments at progressively lower zinc concentrations indicate that the lowest detectable concentration is between 3.65 (Table II) and 2.93 mg/l zinc (Table III) for a 96-hour exposure.

B Fish Breathing

1 Table IV shows the breathing rates of five fish on days 1, 2, and 7 of experiment 8. The first four fish were exposed to a measured zinc concentration of 4.16 mg/l, beginning at 10 a.m. on day 7. The fifth fish served as a control and was not exposed to any added zinc. The amplitude of the breathing signals decreased every night, and the breathing rates for fish 2, in particular, could not be determined during some portions of the dark period (7:30 p.m. - 7:00 a.m.). The maximum breathing rates for each fish during each period of the first day are circled. The breathing rate of any fish during a time period of day 2 or day 7, which is greater than the maximum breathing rate recorded for that fish during the corresponding time period of the first day has a rectangle drawn around it. The total number of fish showing increased breathing is given at the bottom of each column. On day 2, fish 2 showed increased breathing on just two occasions. In contrast after zinc was added on day 7, three and four experimental fish at a time showed increased breathing.

2 Table V summarizes the results of successive comparisons of the first day maximal breathing rates to breathing rates on subsequent days (SCM method of analysis), for experiment 8. During the control period before any zinc was added there were 15 occasions when a single experimental fish responded, and three occasions when two experimental fish responded at the same time. At no time during the control period did more than two fish show responses together. After the zinc was introduced, all four of the exposed fish showed responses simultaneously on five occasions, and three fish showed responses during the same time interval on 19 occasions. If the criterion for detection of water conditions potentially harmful to fish were two or more responses during the same time period, then three false detections would have occurred before any zinc was added, and 4.16 mg/l zinc would have been correctly detected eight hours after it was introduced. If the detection criterion were three or more responses during the same time period, then no false detections would have occurred and the zinc would still have been correctly detected after eight hours.

3 The lowest zinc concentration tested was 2.55 mg/l. Using a detection criterion of simultaneous responses by three fish, this concentration was detected 52 hours after the zinc was added, with no false detections occurring during the four hours before zinc was added (Table VI). The responses of six control fish that were exposed to dilution water containing no added zinc are also shown for comparison. Note that there was no tendency toward increased breathing rates through time in the control fish, and that no more than one control fish showed an increased breathing rate during one time period.

4 Table VII summarizes information on three experiments that indicates the effectiveness of the SCM method of analysis when different criteria for detection are used. Changing the criterion for detection from one to three responses per time period generally increases the lag time and decreases the number of false detections. The lag time is the time from the addition of zinc to the first detection. A false detection is one occurring before any zinc is added to the water.

IV DISCUSSION

A The experiments described above show that the movements and breathing rates of bluegill sunfish can be used to detect sublethal concentrations of zinc. The criterion for detection is a certain number of fish showing an arbitrarily defined response in breathing rate or activity during one time period.

B In choosing a specific criterion for detection, the risk of not detecting stressful conditions soon enough must be weighed against the risk of false detections, and the choice would probably be determined by the nature of the pollutant. If a pollutant is easily detected by the biological monitoring system, is slow-acting, and if the toxic effects are reversible, then the criterion for detection might be responses by 3/4 of the test fish, to avoid the false detections that would necessitate expensive remedial action or a temporary shut-down. On the other hand, an industry that produces an effluent containing a fast-acting toxicant whose effects are irreversible would probably use a criterion that leads to rapid detection (responses by 1/4 to 1/2 of the test fish), and would have to go to the expense of installing holding ponds or recycling facilities to accommodate a relatively high number of false detections. Alternatively, a safety factor could be introduced by metering proportionally more waste into the dilution water delivered to the test fish than is delivered to the stream. The safety factor could be determined by growth and reproduction experiments with fish.

C In an actual industrial situation water and waste qualities are apt to vary unpredictably, and it would certainly be desirable to have a redundant detection system. It is conceivable that some harmful combination of environmental conditions and waste quality would be detected by monitoring one biological function, but not by monitoring another. It is also possible that excessive turbidity would disrupt the light beams of the movement monitor, and not affect the breathing monitor; or that an excessive concentration of electrolytes would affect the electrodes of the breathing monitor, but not affect the activity monitor. Therefore, the activity monitor and the breathing monitor have been combined in our laboratory for further experiments (Fig. 1).

D The rate of data acquisition and analysis could be greatly speeded up if the monitoring system were automated as shown in Figure 2. The sampling rate would be controlled by a minicomputer which could receive data from the movement monitor and the polygraph via a multiplexer as often as every minute. The minicomputer would be programmed to perform statistical analyses every 10 minutes, for example, and output the results on a teleprinter.

E Figure 3 shows how the fish monitoring units would be used at an actual industrial site. A monitoring unit would be located on each waste stream in the plant and on the combined waste stream. The experimental fish in each unit would be exposed to waste diluted with water from the river above the plant, and control fish would be exposed to upstream water alone (Fig. 4). The information from each monitoring unit could be analyzed by a central data processor, and when there was a warning response, the industry could tell which waste stream was at fault. If the problem was outside the plant, the control fish would show responses.

F Figure 5 shows how the in-plant monitoring systems would be integrated into a river management system. The in-plant monitoring units are shown as squares, and in addition to supplying information to each industry, the monitoring units also inform the control center. In such a system, there are several alternative damage prevention measures that could be used, in addition to whatever measures, such as shunting wastes to a holding pond or recycling wastes for further treatment, are available to each industry. If the monitoring units at Industry 2 indicate that toxic waste conditions are developing, then the control center might have Industry 1 hold its waste until the danger of combining wastes from Industry 1 and 2 in the river were alleviated by control measures at Industry 2. Alternatively, the control center might call for a release of water from the upstream dam to dilute the effluent from industry.

G It is likely that "fish sensors" in continuous monitoring units at industrial sites can warn of developing toxic conditions in time to forestall acute damage to the fish populations in streams. In conjunction with stream water quality standards for chronic exposure, such biological monitoring systems should make it possible for healthy fish populations to co-exist with industrial water use.

ACKNOWLEDGEMENT

This research was supported by grants 18050 EDP and 18050 EDQ from the Water Quality Office, Environmental Protection Agency.

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Descriptors:
Environmental Control, Bioassay, Toxicity, Fish Behavior, Fish, Monitoring

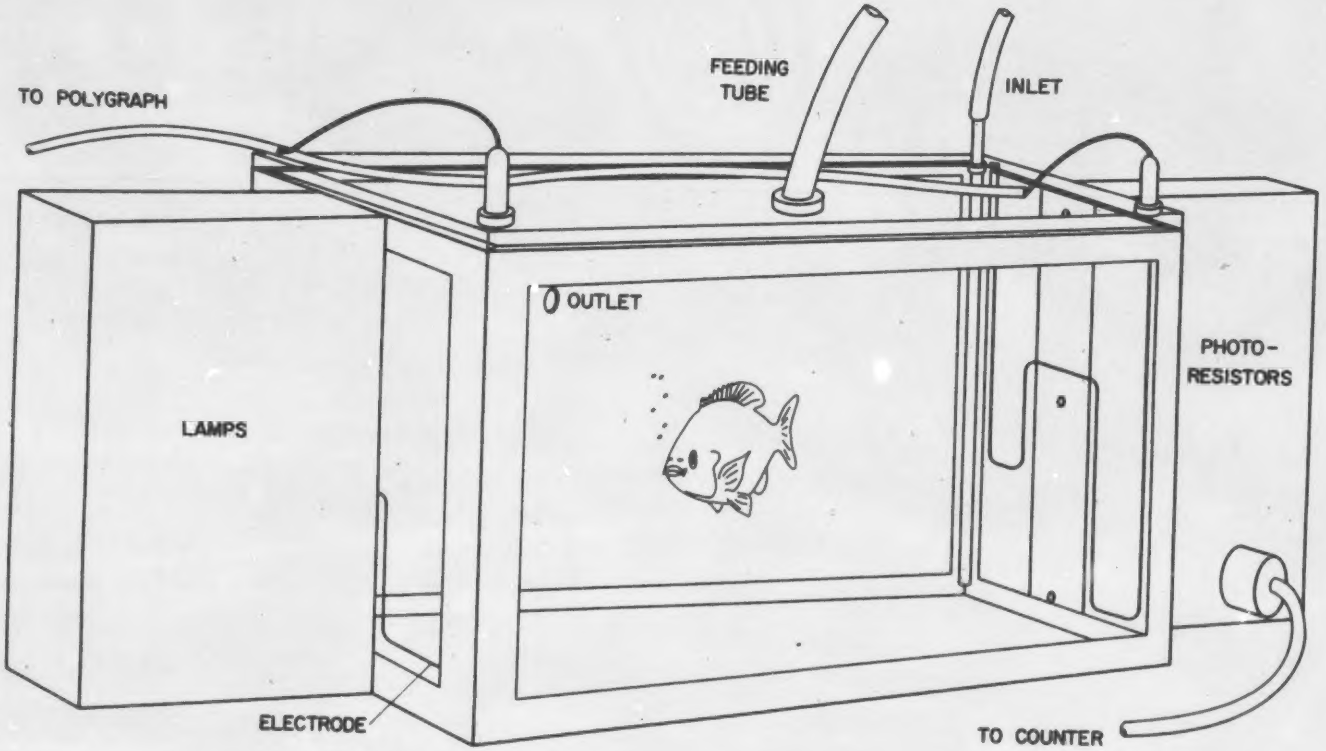

TO POLYGRAPH
FEEDING TUBE
INLET
OUTLET
PHOTO-RESISTORS
LAMPS
ELECTRODE
TO COUNTER

Figure 1. Test chamber for monitoring system, showing the electrodes for recording fish breathing and the light-beam system for recording fish movement.

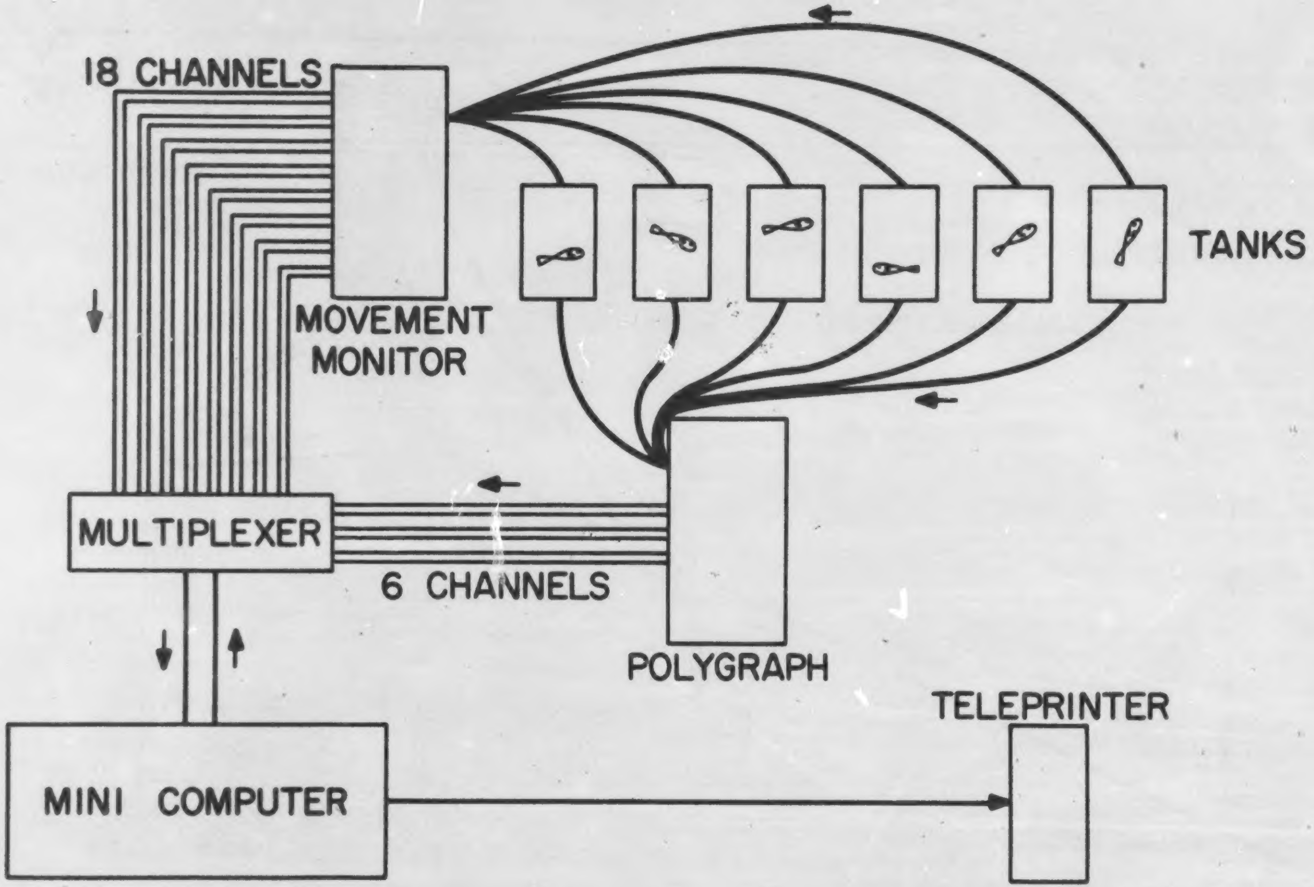

18 CHANNELS
MOVEMENT MONITOR
TANKS
MULTIPLEXER
6 CHANNELS
POLYGRAPH
TELEPRINTER
MINI COMPUTER

Figure 2. An automated fish monitoring unit.

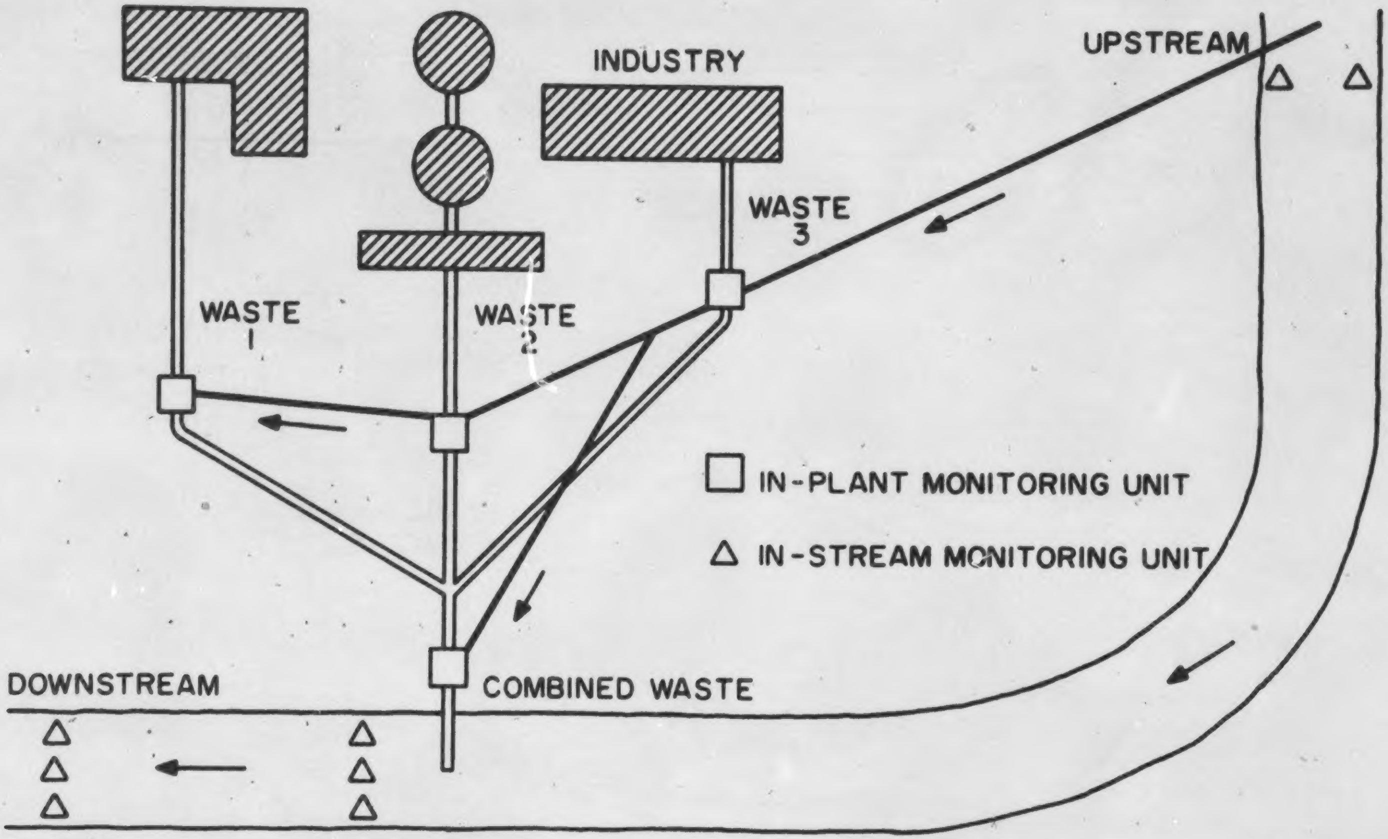

INDUSTRY
UPSTREAM
WASTE 1
WASTE 2
WASTE 3
IN-PLANT MONITORING UNIT
IN-STREAM MONITORING UNIT
DOWNSTREAM
COMBINED WASTE

Figure 3. Arrangement of fish monitoring units at an industrial site.

IN - PLANT MONITORING UNIT

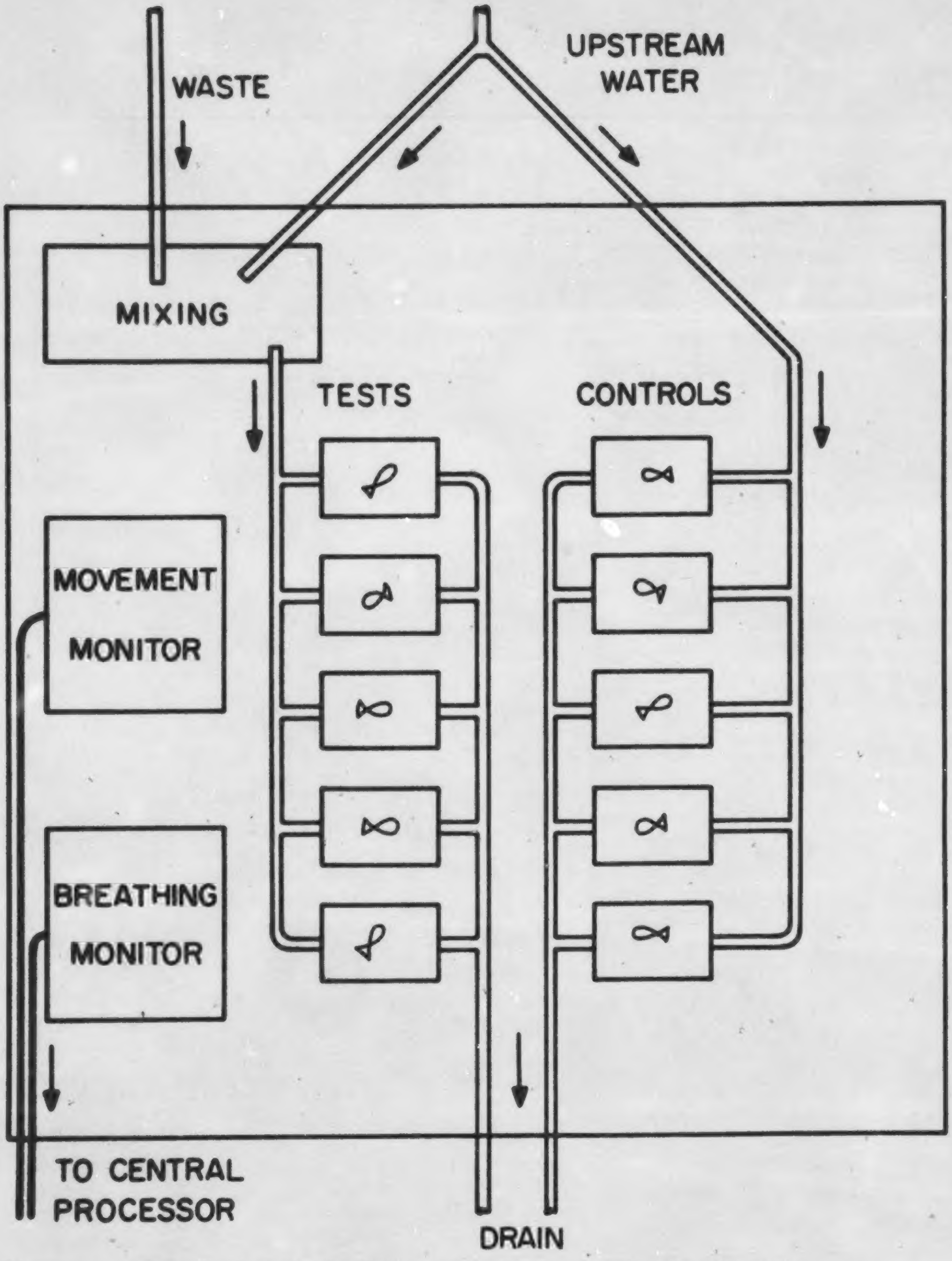

WASTE
UPSTREAM WATER
MIXING
TESTS
CONTROLS
MOVEMENT MONITOR
BREATHING MONITOR
TO CENTRAL PROCESSOR
DRAIN

Figure 4. Detail of a single fish monitoring unit, showing how the experimental fish are exposed to waste diluted with upstream water and the control fish are exposed to upstream water alone.

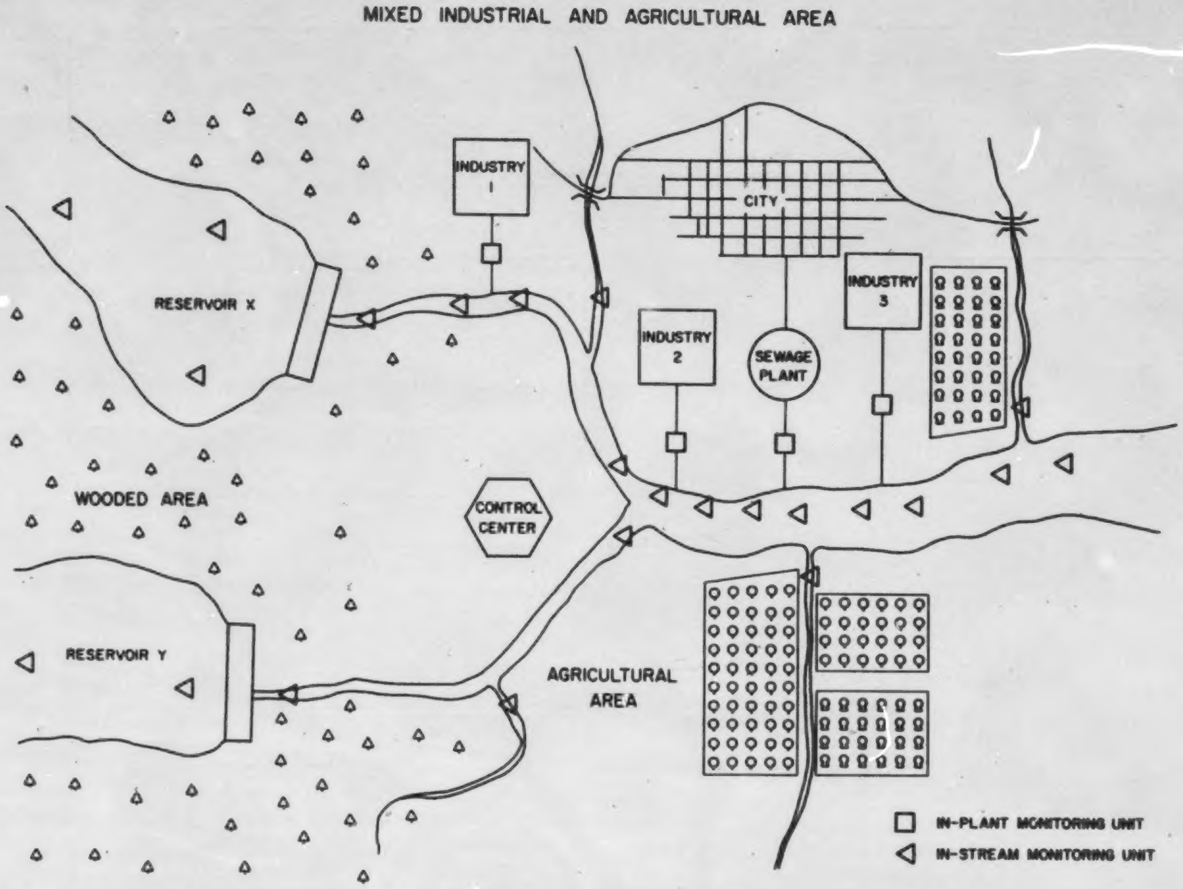

MIXED INDUSTRIAL AND AGRICULTURAL AREA
INDUSTRY 1
CITY
RESERVOIR X
INDUSTRY 3
INDUSTRY 2
SEWAGE PLANT
WOODED AREA
CONTROL CENTER
RESERVOIR Y
AGRICULTURAL AREA
☐ IN-PLANT MONITORING UNIT
◁ IN-STREAM MONITORING UNIT

Figure 5. Use of in-plant monitoring units in a river management system.

USING BENTHIC BIOTA IN WATER QUALITY EVALUATION

I BENTHOS ARE ORGANISMS GROWING ON OR ASSOCIATED PRINCIPALLY WITH THE BOTTOM OF WATERWAYS

Benthos is the noun.

Benthonic, benthal and benthic are adjectives.

II THE BENTHIC COMMUNITY

A Composed of a wide variety of life forms that are related because they occupy "common ground"--substrates of oceans, lakes, streams, etc. Usually they are attached or have relatively weak powers of locomotion. These life forms are:

1 Bacteria

A wide variety of decomposers work on organic materials, breaking them down to elemental or simple compounds.

2 Algae

Photosynthetic plants having no true roots, stems, and leaves. The basic producers of food that nurtures the animal components of the community.

3 Flowering Aquatic Plants (Pondweeds)

The largest flora, composed of complex and differentiated tissues. May be emersed, floating, submersed according to habit.

4 Microfauna

Animals that pass through a U.S. Standard Series No. 30 sieve, but are retained on a No. 100 sieve. Examples are rotifers and microcrustaceans. Some forms have organs for attachment to substrates, while others burrow into soft materials or occupy the interstices between rocks, floral or faunal materials.

5 Meiofauna

Meiofauna occupy the interstitial zone (like between sand grains) in benthic and hyporheic habitats. They are intermediate in size between the microfauna (protozoa and rotifers) and the macrofauna (insects, etc.). They pass a No. 30 sieve (0.5 mm approximately). In freshwater they include nematodes, copepods, tardigrades, naiad worms, and some flat worms. They are usually ignored in freshwater studies, since they pass the standard sieve and/or sampling devices.

6 Macrofauna (macroinvertebrates)

Animals that are retained on a No. 30 mesh sieve (0.5 mm approximately). This group includes the insects, worms, molluscs, and occasionally fish. Fish are not normally considered as benthos, though there are bottom dwellers such as sculpins and darters.

B It is a self-contained community, though there is interchange with other communities. For example: Plankton settles to it, fish prey on it and lay their eggs there, terrestrial detritus leaves are added to it, and many aquatic insects migrate from it to the terrestrial environment for their mating cycles.

C It is stationary water quality monitor. The low mobility of the biotic components requires that they "live with" the quality changes of the over-passing waters. Changes imposed in the long-lived components remain visible for extended periods, even after the cause has been eliminated. Only time will allow a cure for the community by drift, reproduction, and recruitment from the hyporheic zone.

D Between the benthic zone (substrate/water interface) and the underground water table is the hyporheic zone. There is considerable interchange from one zone to another.

III HISTORY OF BENTHIC OBSERVATIONS

A Ancient literature records the vermin associated with fouled waters.

B 500-year-old fishing literature refers to animal forms that are fish food and used as bait.

C The scientific literature associating biota to water pollution problems is over 100 years old (Mackenthun and Ingram, 1964).

D Early this century, applied biological investigations were initiated.

  1 The entrance of state boards of health into water pollution control activities.

  2 Creation of state conservation agencies.

  3 Industrialization and urbanization.

  4 Growth of limnological programs at universities.

E A decided increase in benthic studies occurred in the 1950's and much of today's activities are strongly influenced by developmental work conducted during this period. Some of the reasons for this are:

  1 Movement of the universities from "academic biology" to applied pollution programs.

  2 Entrance of the federal government into enforcement aspects of water pollution control.

  3 A rising economy and the development of federal grant systems.

  4 Environmental Protection Programs are a current stimulus.

IV WHY THE BENTHOS?

A It is a natural monitor

B The community contains all of the components of an ecosystem.

  1 Reducers
    a bacteria
    b fungi

  2 Producers (plants)

  3 Consumers

    a Detritivores and bacterial feeders

    b Herbivores

    c Predators

C Economy of Survey

  1 Manpower

  2 Time

  3 Equipment

D Extensive Supporting Literature

E Advantages of the Macrobenthos

  1 Relatively sessile

  2 Life history length

  3 Fish food organisms

  4 Reliability of Sampling

  5 Dollars/information

  6 Predictability

  7 Universality

F "For subtle chemical changes, unequivocal data, and observations suited to some statistical evaluation will be needed. This requirement favors the macrofauna as a parameter. Macroinvertebrates are easier to sample reproductively than other organisms, numerical estimates are possible and taxonomy needed for synoptic investigations is within the reach of a non-specialist." (Wuhrmann)

G "It is self-evident that for a multitude of non-identifiable though biologically active changes of chemical conditions in rivers, small organisms with high physiological differentiation are most responsive. Thus the small macroinvertebrates (e.g. insects) are doubtlessly the most sensitive organisms for demonstrating unspecified changes of water chemistry called 'pollution'. Progress in knowledge on useful autecological properties of organisms or of transfer of such knowledge into bioassay practice has been very small in the past. Thus, the bioassay concept (relation of organisms in a stream to water quality) in water chemistry has brought not much more than visual demonstration of a few overall chemical effects. Our capability to derive chemical conditions from biological observations is, therefore, almost on the same level as fifty years ago. In the author's opinion it is idle to expect much more in the future because of the limitations inherent to natural bioassay systems (relation of organisms in a stream to water quality)." (Wuhrmann)

V REACTIONS OF THE BENTHIC MACROINVERTEBRATE COMMUNITY TO PERTURBATION

A Destruction of Organism Types

1 Beginning with the most sensitive forms, pollutants kill in order of sensitivity until the most tolerant form is the last survivor. This results in a reduction of variety or diversity of organisms.

2 The generalized order of macroinvertebrate disappearance on a sensitivity scale below pollution sources is shown in Figure 2.

Water Quality Deteriorating ↓

Stoneflies
Mayflies
Caddisflies
Amphipods
Isopods
Midges
Oligochaetes

↑ Water Quality Improving

As water quality improves, these tend to reappear in the same order.

B The Number of Survivors Increase

1 Competition and predation are reduced between different species.

2 When the pollutant is a food (plants, fertilizers, animals, organic materials).

C The Number of Survivors Decrease

1 The material added is toxic or has no food value.

2 The material added produces toxic conditions as a byproduct of decomposition (e.g., large organic loadings produce an anaerobic environment resulting in the production of toxic sulfides, methanes, etc.)

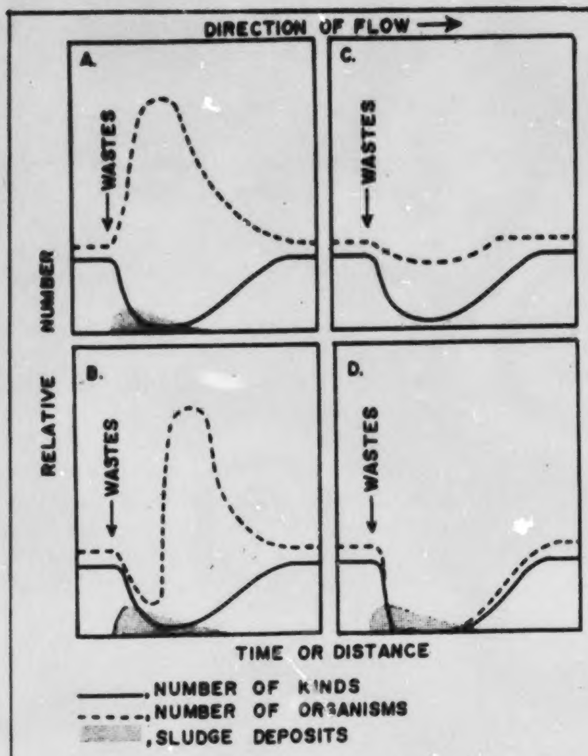
D The Effects May be Manifest in Combinations

1 Of pollutants and their effects.

2 Vary with longitudinal distribution in a stream. (Figure 1)

E Tolerance to Enrichment Grouping (Figure 2)

Flexibility must be maintained in the establishment of tolerance lists based on the response of organisms to the environment because of complex relationships among varying environmental conditions. Some general tolerance patterns can be established. Stonefly and mayfly nymphs, hellgrammites, and caddisfly larvae represent a grouping (sensitive or intolerant) that is generally quite sensitive to environmental changes. Blackfly larvae, scuds, sowbugs, snails, fingernail clams, dragonfly and damselfly naiads, and most kinds of midge larvae are facultative (or intermediate) in tolerance. Sludge-worms, some kinds of midge larvae (bloodworms), and some leeches



Four basic responses of bottom animals to pollution. A. Organic wastes eliminate the sensitive bottom animals and provide food in the form of sludges for the surviving tolerant forms. B. Large quantities of decomposing organic wastes eliminate sensitive bottom animals and the excessive quantities of byproducts of organic decomposition inhibit the tolerant forms; in time, with natural stream purification, water quality improves so that the tolerant forms can flourish, utilizing the sludges as food. C. Toxic materials eliminate the sensitive bottom animals; sludge is absent and food is restricted to that naturally occurring in the stream, which limits the number of tolerant surviving forms. Very toxic materials may eliminate all organisms below a waste source. D. Organic sludges with toxic materials reduce the number of kinds by eliminating sensitive forms. Tolerant survivors do not utilize the organic sludges because the toxicity restricts their growth.

Figure 1

are tolerant to comparatively heavy loads of organic pollutants. Sewage mosquitoes and rat-tailed maggots are tolerant of anaerobic environments for they are essentially air-breathers.

F Structural Limitations

1 The morphological structure of a species limits the type of environment it may occupy.

a Species with complex appendages and exposed complicated respiratory structures, such as stonefly nymphs, mayfly nymphs, and caddisfly larvae, that are subjected to a constant deluge of setteable particulate matter soon abandon the polluted area because of the constant preening required to maintain mobility or respiratory functions; otherwise, they are soon smothered.

b Benthic animals in depositing zones may also be burdened by "sewage fungus" growths including stalked protozoans. Many of these stalked protozoans are host specific.

2 Species without complicated external structures, such as bloodworms and sludgeworms, are not so limited in adaptability.

a A sludgeworm, for example, can burrow in a deluge of particulate organic matter and flourish on the abundance of "manna."

b Morphology also determines the species that are found in riffles, on vegetation, on the bottom of pools, or in bottom deposits.

VI SAMPLING PROCEDURES

A Fauna

1 Qualitative sampling determines the variety of species occupying an area. Samples may be taken by any method that will capture representatives of the species present. Collections from such samplings indicate changes in the environment, but generally do not accurately reflect the degree of change. Mayflies, for example, may be reduced from 100 to 1 per square meter. Qualitative data would indicate the presence of both species, but might not necessarily delineate the change in predominance from mayflies to sludgeworms. The stop net or kick sampling technique is often used.

2 Quantitative sampling is performed to observe changes in predominance. The most common quantitative sampling tools are the Petersen, Ekman, and Ponak grabs and the Surber stream bottom or square-foot sampler. Of these, the Petersen grab samples the widest variety of substrates. The Ekman grab is limited to fine-textured and soft substrates, such as silt and sludge, unless hydraulically operated.

The Surber sampler is designed for sampling riffle areas; it requires moving water to transport dislodged organisms into its net and is limited to depths of two feet or less.

Kick samples of one minute duration will usually yield around 1,000 macroinvertebrates per square meter (10.5 X a one minute kick= organisms/m^2).

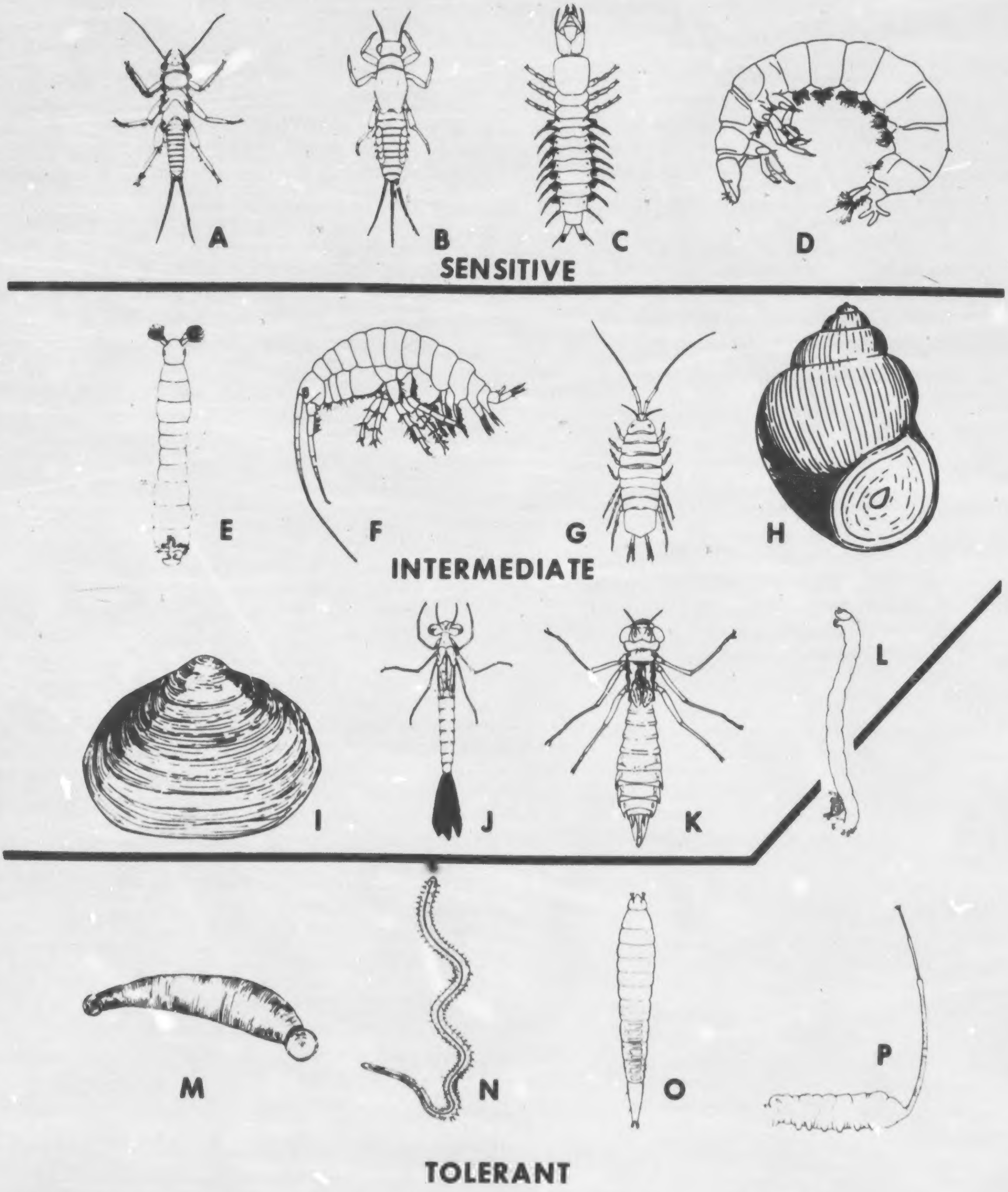
3 Manipulated substrates (often referred to as "artificial substrates") are placed in a stream and left for a specific time period. Benthic macroinvertebrates readily colonize these forming a manipulated community. Substrates may be constructed of natural materials or synthetic; may be placed in a natural situation or unnatural; and may or may not resemble the normal stream community. The point being that a great number of environmental variables are standardized and thus upstream and downstream stations may be legitimately compared in terms of water quality of the moving water column. They naturally do not evaluate what may or may not be happening to the substrate beneath said monitor. The latter could easily be the more important.

REPRESENTATIVE BOTTOM-DWELLING MACROANIMALS

Drawings from Geckler, J., K.M. Mackenthun and W.M. Ingram, 1963. Glossary of Commonly Used Biological and Related Terms in Water and Waste Water Control, DHEW, PHS, Cincinnati, Ohio, Pub. No. 999-WP-2.

A	Stonefly nymph	(Plecoptera)
B	Mayfly nymph	(Ephemeroptera)
C	Hellgrammite or Dobsonfly larvae	(Megaloptera)
D	Caddisfly larvae	(Trichoptera)
E	Black fly larvae	(Simuliidae)
F	Scud	(Amphipoda)
G	Aquatic sowbug	(Isopoda)
H	Snail	(Gastropoda)
I	Fingernail clam	(Sphaeriidae)
J	Damselfly naiad	(Zygoptera)
K	Dragonfly naiad	(Anisoptera)
L	Bloodworm or midge fly larvae	(Chironomidae)
M	Leech	(Hirudinea)
N	Sludgeworm	(Tubificidae)
O	Sewage fly larvae	(Psychodidae)
P	Rat-tailed maggot	(Tubifera-Eristalis)

KEY TO FIGURE 2


A
B
C
D
SENSITIVE
E
F
G
H
INTERMEDIATE
I
J
K
L
M
N
O
P
TOLERANT

4 Invertebrates which are part of the benthos, but under certain conditions become carried downstream in appreciable numbers, are known as Drift.

Groups which have members forming a conspicuous part of the drift include the insect orders Ephemeroptera, Trichoptera, Plecoptera and the crustacean order Amphipoda.

Drift net studies are widely used and have a proven validity in stream water quality studies.

5 The collected sample is screened with a standard sieve to concentrate the organisms; these are sorted from the retained material, and the number of each kind determined. Data are then adjusted to number per unit area, usually to number of bottom organisms per square meter.

6 Independently, neither qualitative not quantitative data suffice for thorough analyses of environmental conditions. A cursory examination to detect damage may be made with either method, but a combination of the two gives a more precise determination. If a choice must be made, quantitative sampling would be best, because it incorporates a partial qualitative sample.

7 Studies have shown that a significant number and variety of macroinvertebrates inhabit the hyporheic zone in streams. As much as 80% of the macroinvertebrates may be below 5 cm in this hyporheic zone. Most samples and sampling techniques do not penetrate the substrate below the 5 cm depth. All quantitative studies must take this and other substrate factors into account when absolute figures are presented on standing crop and numbers per square meter, etc.

B Flora

1 Direct quantitative sampling of naturally growing bottom algae is difficult. It is basically one of collecting algae from a standard or uniform area of the bottom substrates without disturbing the delicate growths and thereby distort the sample. Indirect quantitative sampling is the best available method.

2 Manipulated substrates, such as wood blocks, glass or plexiglass slides, bricks, etc., are placed in a stream. Bottom-attached algae will grow on these artificial substrates. After two or more weeks, the artificial substrates are removed for analysis. Algal growths are scraped from the substrates and the quantity measured. Since the exposed substrate area and exposure periods are equal at all of the sampling sites, differences in the quantity of algae can be related to changes in the quality of water flowing over the substrates.

VII ANALYSES OF MICROFLORA

A Enumeration

1 The quantity of algae on manipulated substrates can be measured in several ways. Microscopic counts of algal cells and dry weight of a algal material are long established methods.

2 Microscopic counts involve thorough scraping, mixing and suspension of the algal cells. From this mixture an aliquot of cells is withdrawn for enumeration under a microscope. Dry weight is determined by drying and weighing the algal sample, then igniting the sample to burn off the algal materials, leaving inert inorganic materials that are again weighed. The difference between initial dry weight and weight after ignition is attributed to algae.

3 Any organic sediments, however, that settle on the substrate along with the algae are processed also.

Thus, if organic wastes are present appreciable errors may enter into this method.

B Chlorophyll Analysis

1 During the past decade, chlorophyll analysis has become a popular method for estimating algal growth. Chlorophyll is extracted from the algae and is used as an index of the quantity of algae present. The advantages of chlorophyll analysis are rapidity, simplicity, and vivid pictorial results.

2 The algae are scrubbed from the artificial substrate samples, ground, then each sample is steeped in equal volumes, 90% aqueous acetone, which extracts the chlorophyll from the algal cells. The chlorophyll extracts may be compared visually.

3 Because the cholorophyll extracts fade with time, colorimetry should be used for permanent records. For routine records, simple colorimeters will suffice. At very high cholorophyll densities, interference with colorimetry occurs, which must be corrected through serial dilution of the sample or with a nomograph.

C Autotrophic Index

The chlorophyll content of the periphyton is used to estimate the algal biomass and as an indicator of the nutrient content (or trophic Status) or toxicity of the water and the taxonomic composition of the community. Periphyton growing in surface water relatively free of organic pollution consists largely of algae, which contain approximately 1 to 2 percent chlorophyll a by dry weight. If dissolved or particulate organic matter is present in high concentrations, large populations of filamentous bacteria, stalked protozoa, and other nonchlorophyll bearing microorganisms develop and the percentage of chlorophyll is then reduced. If the biomass-chlorophyll a relationship is expressed as a ration (the autotrophic index), values greater than 100 may result from organic pollution (Weber and McFarland, 1969; Weber, 1973).

$$\text{Autotrophic Index} = \frac{\text{Ash-free Wgt (mg/m}^2\text{)}}{\text{Chlorophyll a (mg/m}^2\text{)}}$$

VIII MACROINVERTEBRATE ANALYSES

A Taxonomic

The taxonomic level to which animals are identified depends on the needs, experience, and available resources. However, the taxonomic level to which identifications are carried in each major group should be constant throughout a given study.

B Biomass

Macroinvertebrate biomass (weight of organisms per unit area) is a useful quantitative estimation of standing crop.

C Reporting Units

Data from quantitative samples may be used to obtain:

1 Total standing crop of individuals, or biomass, or both per unit area or unit volume or sample unit, and

2 Numbers of biomass, or both, of individual taxa per unit area or unit volume or sample unit.

3 Data from devices sampling a unit area of bottom will be reported in grams dry weight or ash-free dry weight per square meter (gm/m^2), or numbers of individuals per square meter, or both.

4 Data from multiplate samplers will be reported in terms of the total surface area of the plates in grams dry weight or ash-free dry weight or numbers of individuals per square meter, or both.

5 Data from rock-filled basket samplers will be reported as grams dry weight or numbers of individuals per sampler, or both.

IX FACTORS INVOLVED IN DATA INTERPRETATION

Two very important factors in data evaluation are a thorough knowledge of conditions under which the data were collected and a critical assessment of the reliability of the data's representation of the situation.

A Maximum-Minimum Values

The evaluation of physical and chemical data to determine their effects on aquatic organisms is primarily dependent on maximum and minimum observed values. The mean is useful only when the data are relatively uniform. The minimum or maximum values usually create acute conditions in the environment.

B Identification

Precise identification of organisms to species requires a specialist in limited taxonomic groups. Many immature aquatic forms have not been associated with the adult species. Therefore, one who is certain of the genus but not the species should utilize the generic name, not a potentially incorrect species name. The method of interpreting biological data on the basis of numbers of kinds and numbers of organisms will typically suffice.

C Lake and Stream Influence

Physical characteristics of a body of water also affect animal populations. Lakes or impounded bodies of water support different faunal associations from rivers. The number of kinds present in a lake may be less than that found in a stream because of a more uniform habitat. A lake is all pool, but a river is composed of both pools and riffles. The nonflowing water of lake exhibits a more complete settling of particulate organic matter that naturally supports a higher population of detritus consumers. For these reasons, the bottom fauna of a lake or impoundment, or stream pool cannot be directly compared with that of a flowing stream riffle.

D Extrapolation

How can bottom-dwelling macrofauna data be extrapolated to other environmental components? It must be borne in mind that a component of the total environment is being sampled. If the sampled component exhibits changes, then so must the other interdependent components of the environment. For example, a clean stream with a wide variety of desirable bottom organisms would be expected to have a wide variety of desirable bottom fishes; when pollution reduces the number of bottom organisms, a comparable reduction would be expected in the number of fishes. Moreover, it would be logical to conclude that any factor that eliminates all bottom organisms would eliminate most other aquatic forms of life. A clean stream with a wide variety of desirable bottom organisms would be expected to permit a variety of recreational, municipal and industrial uses.

E Expression of Data

1 Standing crop and taxonomic composition

Standing crop and numbers of taxa (types or kinds) in a community are highly sensitive to environmental perturbations resulting from the introduction of contaminants. These parameters, particularly standing crop, may vary considerably in unpolluted habitats, where they may range from the typically high standing crop of littoral zones of glacial lakes to the sparse fauna of torrential soft-water streams. Thus, it is important that comparisons are made only between truly comparable environments.

2 Diversity

Diversity indices are an additional tool for measuring the quality of the environment and the effect of induced stress on the structure of a community of macroinvertebrates. Their use is based on the generally observed phenomenon that relatively undisturbed environments support communities having large numbers of species with no individual species present in overwhelming abundance. If the species in such a community are ranked on the basis of their numerical abundance, there will be relatively few species with large numbers of individuals and large numbers of species represented by only a few individuals. Many forms of stress tend to reduce diversity by making the environment unsuitable for some species or by giving other species a competitive advantage.

3 Indicator-organism scheme (rat-tailed maggot studies)

a For this technique, the individual taxa are classified on the basis of their tolerance or intolerance to various levels of putrescible wastes. Taxa are classified according to their presence or absence of different environments as determined by field studies. Some reduce data based on the presence or absence of indicator organisms to a simple numerical form for ease in presentation.

b "Biologists are engaging in fruitless exercise if they intend to make any decisions about indicator organisms by operating at the generic level of macroinvertebrate identifications." (Resh and Unzicker)

4 Reference station methods

Comparative or control station methods compare the qualitative characteristics of the fauna in clean water habitats with those of fauna in habitats subject to stress. Stations are compared on the basis of richness of species.

If adequate background data are available to an experienced investigator, these techniques can prove quite useful—particularly for the purpose of demonstrating the effects of gross to moderate organic contamination on the macroinvertebrate community. To detect more subtle changes in the macroinvertebrate community, collect quantitative data on numbers or biomass of organisms. Data on the presence of tolerant and intolerant taxa and richness of species may be effectively summarized for evaluation and presentation by means of line graphs, bar graphs, pie diagrams, histograms, or pictoral diagrams.

X IMPORTANT ASSOCIATED ANALYSES

A The Chemical Environment

1 Dissolved oxygen

2 Nutrients

3 Toxic materials

4 Acidity and alkalinity

5 Etc.

B The Physical Environment

1 Suspended solids

2 Temperature

3 Light penetration

4 Sediment composition

5 Etc.

XI AREAS IN WHICH BENTHIC STUDIES CAN BEST BE APPLIED

A Damage Assessment or Stream Health

If a stream is suffering from abuse the biota will so indicate. A biologist can determine damages by looking at the "critter" assemblage in a matter of minutes. Usually, if damages are not found, it will not be necessary to alert the remainder of the agency's staff.

pack all the equipment, pay travel and per diem, and then wait five days before enough data can be assembled to begin evaluation.

B By determining what damages have been done, the potential cause "list" can be reduced to a few items for emphasis and the entire "wonderful worlds" of science and engineering need not be practiced with the result that much data are discarded later because they were not applicable to the problem being investigated.

C Good benthic data associated with chemical, physical, and engineering data can be used to predict the direction of future changes and to estimate the amount of pollutants that need to be removed from the waterways to make them productive and useful once more.

D The benthic macroinvertebrates are an easily used index to stream health that citizens may use in stream improvement programs. "Adopt-a-stream" efforts have successfully used simple macroinvertebrate indices.

E The potential for restoring biological integrity in our flowing streams using macroinvertebrates has barely been touched.

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Descriptors: Aquatic Life, Benthos, Water Quality, Degradation, Environmental Effects, Trophic Level, Biological Communities, Ecological Distributions

THE INTERPRETATION OF BIOLOGICAL DATA WITH REFERENCE TO WATER QUALITY

I INTRODUCTION

Sanitary engineers like to have data presented to them in a readily assimilable form and some of them seem a little impatient with biologists who appear unable to provide definite quantitative criteria applicable to all kinds of water conditions. I think the feeling tends to be that this is the fault of biologists, and if they would only pull themselves out of the scientific stone-age all would be well. I will try to explain here why I believe that biological data can never be absolute nor interpretable without a certain amount of expertise. In this respect biologists resemble medical men who make their diagnoses against a complex background of detailed knowledge. Anyone can diagnose an open wound but it takes a doctor to identify an obscure disease; and although he can explain how he does it he cannot pass on his knowledge in that one explanation. Similarly, one does not need an expert to recognize gross organic pollution, but only a biologist can interpret more subtle biological conditions in a water body; and here again he can explain how he does it, but that does not make his hearer a biologist. Beck (1957) said something similar at a previous symposium in Cincinnati in 1956.

II THE COMPLEXITY OF BIOLOGICAL REACTIONS TO WATER CONDITIONS

A Complexity of the Aquatic Habitat

The aquatic habitat is complex and consists not only of water but of the substrata beneath it, which may be only indirectly influenced by the quality of the water. Moreover, in biological terms, water quality includes such features as rate of flow and temperature regime, which are not considered of direct importance by the chemist. To many animals and plants, maximum summer temperature or maximum rate of flow is just as important as minimum oxygen tension. The result is that inland waters provide an enormous array of different combinations of conditions, each of which has its own community of plants and animals; and the variety of species involved is very great. Thus, for example, Germany has about 6000 species of aquatic animals (Illies 1961a) and probably at least as many species of plants. Yet Europe has a rather restricted fauna because of the Pleistocene ice age; in most other parts of the world the flora and fauna are even richer.

B Distribution of Species and Environmental Factors

We know something about the way in which species are distributed in the various habitats, especially in the relatively much studied continent of Europe, but we have, as yet, little idea as to what factors or combination of factors actually control the individual species.

1 Important ecological factors

Thus, it is possible to list the groups of organisms that occur in swift stony upland rivers (rhithron in the sense of Illies, 1961b) and to contrast them with those of the lower sluggish reaches (potamon). Similarly we know, more or less, the different floras and faunas we can expect in infertile (oligotrophic) and fertile (eutrophic) lakes. We are, however, much less informed as to just what ecological factors cause these differences. We know they include temperature and its yearly amplitude; oxygen, particularly at minimal levels; plant nutrients, such as nitrate, phosphate, silica, and bicarbonate; other ions in solution, including calcium, chloride, and possibly hydrogen; dissolved organic matter, which is necessary for some bacteria and fungi and probably for some algae; the nature of the substratum; and current.

2 Complexity of interacting factors

We also know these factors can interact in a complex manner and that their action on any particular organism can be indirect through other members of the biota.

a Induced periphyton growths

Heavy growths of encrusting algae induced by large amounts of plant nutrients, or of bacteria induced by ample supplies of organic matter, can eliminate or decimate populations of lithophile insects by simple mechanical interference. But the change does not stop there: the growths themselves provide habitats for the animals, such as Chironomidae and Naidid worms, which could not otherwise live on the stones.

b Oxygen levels and depositing substrates

If oxygen conditions over a muddy bottom reach levels just low enough to be intolerable to leeches, tubificid worms, which the leeches normally hold in check, are able to build up to enormous numbers especially as some of their competitors (e.g. Chironomus) are also eliminated.

c Oxygen levels and non muddy substrates

One then finds the typical outburst of sludge worms, so often cited as indicators of pollution. This does not happen if the same oxygen tension occurs over sand or rock, however, as these are not suitable substrata for the worms. Many such examples could be given, but they would only be ones we understand; there must be a far greater number about which we know nothing.

d One must conclude, therefore, that quite simple chemical changes can produce far-reaching biological effects; that we only understand a small proportion of them; and that they are not always the same.

3 Classic examples

This seems like a note of despair, however, if water quality deviates too far from normal, the effects are immediately apparent. Thus, poisonous substances eliminate many species and may leave no animals (Hynes 1960); excessive quantities of salt remove all leeches, amphipods, and most insects and leave a fauna consisting largely of Chironomidae, caddis worms, and oligochaetes (Albrecht 1954) and excessive amounts of dissolved organic matter give rise to carpets of sewage fungus, which never occur naturally. Here no great biological expertise is needed, and there is little difficulty in the communication of results. It is when effects are slighter and more subtle that biological findings become difficult to transmit intelligibly to other disciplines.

III THE PROBLEMS IN PRESENTATION OF BIOLOGICAL RESULTS

Because of these difficulties various attempts have been made to simplify the presentation of biological findings, but to my mind none of them is very successful because of the complexity of the subject. Early attempts at systematization developed almost independently on the two sides of the Atlantic, although they had some similarities.

A Early Studies in the United States (Richardson and the Illinois River)

In America, there was a simple division into zones of pollution, e.g. degradation, septic, and recovery, which were characterized in broad general terms. This simple, textbook approach is summarized by Whipple et al. (1947), and serves fairly well for categorizing gross organic pollution such as has been mentioned above. It was, however, soon found by Richardson (1929) during his classical studies on the Illinois River that typical "indicators" of foul conditions, such as Tubificidae and Chironomus, were not always present where they would be expected to occur. This was an early indication that it is not the water quality itself that provides suitable conditions for "pollution faunas," but other, usually associated, conditions - in this instance deposits of rich organic mud. Such conditions may, in fact, be present in places where water quality in no way resembles pollution, e.g., upstream of weirs in trout streams where autumn leaves accumulate and decay and cause the development of biota typical of organically polluted water. Samples must therefore be judged against a background of biological knowledge. Richardson was fully aware of this and was in no doubt about the condition of the Illinois River even in places where his samples showed few or no pollution indicators.

B The European Saprobic System

In Europe, the initial stress was primarily on microorganisms and results were first codified in the early years of the century by Kolkwitz and Marsson. In this "Saprobiensystem," zones of organic pollution similar to those described by the American workers were defined and organisms were listed as characteristic of one or more zones;

TABLE 1

SAPROBIENSYSTEM - A European system of classifying organisms according to their response to the organic pollution in slow moving streams. (22)

Alpha-Mesosaprobic Zone - Area of active decomposition, partly aerobic, partly anaerobic, in a stream heavily polluted with organic wastes.

Beta-Mesosaprobic Zone - That reach of stream that is moderately polluted with organic wastes.

Oligosaprobic Zone - That reach of a stream that is slightly polluted with organic wastes and contains the mineralized products of self-purification from organic pollution, but with none of the organic pollutants remaining.

Polysaprobic Zone - That area of a grossly polluted stream which contains the complex organic wastes that are decomposing primarily by anaerobic processes.

A recent exposition of this list is given by Kolkwitz (1950). It was then claimed that with a list of the species occurring at a particular point it was possible to allocate it to a saprobic zone. This system early met with criticism for several reasons. First,

TABLE 2

SAPROBICITY LEVELS ACCORDING TO THE TROPHIC STRUCTURE OF THE COMMUNITIES OF ORGANISMS

Saprobicity Level	Structure of the Communities of Organisms
I β-oligosaprobic	Balanced relationship between producers, consumers and destroyers; the communities of organisms are poor in individuals but there is a moderate variety of species, small biomass and low bioactivity.
II α-oligosaprobic	Balanced relationship between producers, consumers and destroyers; communities of organisms are rich in individuals and species with a large biomass and high bioactivity.
III β-mesosaprobic	Substantially balanced relationship between producers, consumers and destroyers; a relative increase in the abundance of destroyers and, accordingly, of the consumers living off them; communities of organisms are rich in individuals and species with a large biomass and high bioactivity.
IV α-mesosaprobic	Producers decline as compared with an increase in consumers and destroyers; mixotrophic and amphitrophic forms predominate among the producers; communities of organisms rich in individuals but poor in species with a large biomass and extremely high bioactivity; still only few species of macro-organisms; mass development of bacteria and bacteria-eating ciliates.
V β-polysaprobic	Producers drastically decline; communities of organisms are extremely rich in individuals but poor in species with a large biomass and high bioactivity; macrofauna represented only by a few species of tubificids and chironomids; as in IV these are in great abundance; mass development of bacteria and bacteria-eating ciliates.
VI α-polysaprobic	Producers are absent; the total biomass is formed practically solely by anaerobic bacteria and fungi; macro-organisms are absent; flagellates outnumber ciliates amongst the protozoa.

Saprobicity - "Within the bioactivity of a body of water, Saprobicity is the sum total of all those metabolic processes which are the antithesis of primary production. It is therefore the sum total of all those processes which are accompanied by a loss of potential energy." Part I, Prague Convention.

all the organisms listed occurred in natural habitats--they were not evolved in polluted water--and there was much doubt as to the placing of many of the species in the lists. The system, however, did serve to codify ecological knowledge about a long list of species along an extended trophic scale. Its weaknesses appeared to be merely due to lack of knowledge; such a rigid system took far too little account of the complexity of the reaction of organisms to their habitats. For instance, many organisms can be found, albeit rarely, in a wide range of conditions and others may occur in restricted zones for reasons that have nothing to do with water quality. We often do not know if organisms confined to clean headwaters are kept there by high oxygen content, low summer temperatures, or inability to compete with other species under other conditions. In the swift waters of Switzerland the system broke down in that some organisms appeared in more polluted zones than their position in the lists would indicate. Presumably here the controlling factor was oxygen, which was relatively plentiful in turbulent cold water. In a recent series of experiments, Zimmerman (1962) has proven that current alone has a great influence on the biota, and identically polluted water flowing at different speeds produces biotic communities characteristic of different saprobic levels. He finds this surprising, but to me it seems an expected result, for the reasons given above.

C Recent Advances in the Saprobic System

1 Perhaps Zimmerman's surprise reflects the deeply rooted entrenchment of the Saprobiensystem in Central Europe. Despite its obvious shortcomings it has been revised and extended. Liebmann (1951) introduced the concept of considering number as well as occurrence and very rightly pointed out that the community of organisms is what matters rather than mere species lists. But he did not stress the importance of extrinsic factors, such as current, nor that the system can only apply to organic pollution and that different types of organic pollution differ in their effects; e.g., carbohydrate solutions from paper works produce different results from those of sewage, as they contain little nitrogen and very different suspended solids. Other workers (Sladecek 1961 and references therein) have subdivided the more polluted zones, which now, instead of being merely descriptive, are considered to represent definite ranges of oxygen content, BOD, sulfide, and even E. coli populations. Every water chemist knows that BOD and oxygen content are not directly related and to assume that either should be more than vaguely related to the complexities of biological reactions seems to me to indicate a fundamental lack of ecological understanding. I also think it is damaging to the hope of mutual understanding between the various disciplines concerned with water quality to give the impression that one can expect to find a close and rigid relationship between water quality measurements as assessed by different sets of parameters. Inevitably these relationships vary with local conditions; what applies in a sluggish river in summer will certainly not apply to a mountain stream or even to the same river in the winter. Correlation of data, even within one discipline, needs understanding, knowledge, and judgment.

2 Caspers and Schulz (1960) showed that the failure of the system to distinguish between waters that are naturally productive and those artifically enriched can lead to absurd results. They studied a canal in Hamburg, which because of its urban situation can only be regarded as grossly polluted. Yet it develops a rich plankton,

the composition of which, according to the system, shows it to be virtually clean.

D Numerical Application of the Saprobic System

Once the Saprobiensystem was accepted it was logical to attempt to reduce its findings to simple figures or graphs for presentation of results. Several such methods were developed, which are described by Tumpling (1960), who also gives the original references. In all these methods, the abundance of each species is recorded on some sort of logarithmic scale (e.g. 1 for present, 3 for frequent, 5 for common, etc.). The sums of these abundances in each saprobic level are plotted on graphs, the two most polluted zones showing as negative and others as positive. Or, the various saprobic levels are given numerical values [1 for oligosaprobic (clean), 2 for β-mesosaprobic, etc.] and the rating for each species is multiplied by its abundance number. The sum of all these products divided by the sum of all the frequencies gives a "saprobic index" for the locality. Clearly the higher this number, the worse the water quality in terms of organic pollution. In a similar way the so-called "relative Belastung" (relative load) is calculated by expressing the sums of all the abundances of organisms characteristic of the two most-polluted zones as a percentage of the sum of all abundances. Then 100 percent is completely polluted water, and clean localities will give a low number.

E Weaknesses of the Saprobic System

There are various elaborations of these methods, such as sharing of species between zones and taking account of changes in base-line as one passes downstream. None of them, however, eliminates the basic weaknesses of the system nor the fact that, as Caspers and Schulz (1960) point out, there is little agreement between the various authors in the assignment of species to the different levels. Therefore, one gains a number or a figure that looks precise and is easily understood, but it is based on very dubious foundations.

F Comparative North American Systems

Similar systems are indigenous to North America, but were independently evolved.

1 Wurtz (1955) and Wurtz and Dolan (1960) describe a system whereby animals are divided into sensitive-to-pollution and non-sensitive (others are ignored), and also into burrowing, sessile, and foraging species (six classes).

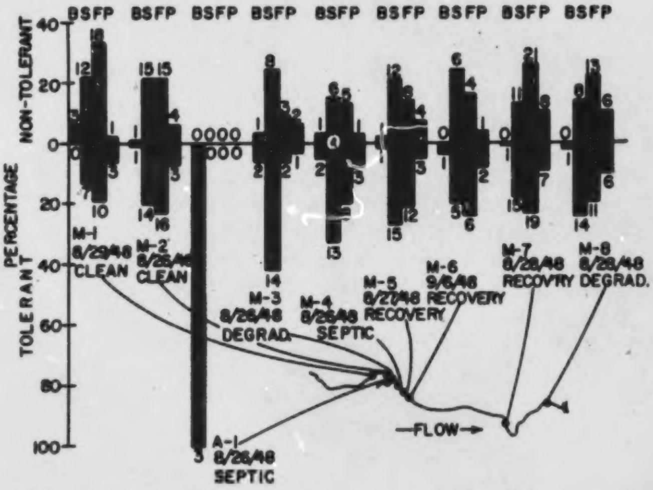

Figure 1. Histograms, based on selected organisms, illustrating stream reaches of clean, degradation, septic, and recovery conditions [after Wurtz] (22)

Numbers of these species represented are plotted for each station as six histograms on the basis of percentage of total number of species. If the constitution of the fauna from control stations or from similar localities is known, it is possible to express numerically "biological depression" (i.e., percentage reduction in total number of species), "biological distortion" (changes in proportions of tolerant and non-tolerant species), and "biological skewness" (changes in the ratios of the three habitat classes). Such results must, of course, be evaluated, and the definition of tolerance is quite subjective; but the method has the advantages of simplicity and dependence on control data. Like the Saprobiensystem, however, it can have no universal validity. It also suffers from the fact that it takes no account of numbers; a single specimen, which may be there by accident, carries as much weight as a dense population.

2 Patrick (1949) developed a similar system in which several clean stations on the water body being investigated are chosen, and the average number of species is determined occurring in each of seven groups of taxa chosen because of their supposed reaction to pollution. These are then plotted as seven columns of equal height, and data from other stations are plotted on the same scale; it is assumed that stations differing markedly from the controls will show biological imbalance in that the columns will be of very unequal heights. Number is indicated by double width in any column containing species with an unusual number of individuals.
I have already questioned the usefulness of this method of presentation (Hynes 1960), and doubt whether it gives any more readily assimilable data than simple tabulation; it does however, introduce the concept of ecological imbalance.

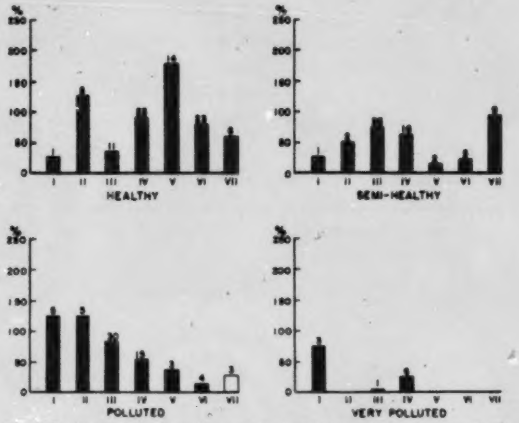

Figure 2. Histograms, based on selected organisms, illustrating healthy, semi-healthy, polluted, and very polluted stations in Conestoga Basin, Pa. [after Patrick] (22)

TABLE 3 —Classification of Groups of Organisms Shown in Figure 2

GROUP	ORGANISM
I	Blue-green algae; green algae of the genera *Stigeoclonium*, *Spirogyra*, and *Tribonema*; the bdelloid rotifers plus *Cephalodella megalocephala* and *Proales decipiens*
II	Oligochaetes, leeches, and pulmonate snails
III	Protozoa
IV	Diatoms, red algae, and "most of the green algae"
V	All rotifers not included in Group I, clams, gill-breathing snails, and tricladid flatworms
VI	All insects and crustacea
VII	All fish

3 Beak (1964), another author, recognized the need for a concise expression of pollution based on biological information. Toward this end, he developed a method of biological scoring which is based on the frequency of occurrence of certain macroscopic invertebrates obtained from 6 years of study on one river. It will be noted that the Biological Score is a modification and expansion of Beck's Biotic Index.

The indicator organisms are divided into three categories: Group I contains the pollution-tolerant species; Group II comprises those species which are facultative with respect to pollution; and Group III contains the pollution-intolerant forms. Each group is assigned a weighted score that can be allotted to field samples on the following basis:

a Normal complement of Group III scores 3 points.

b Normal complement of Group II scores 2 points.

c Normal complement of Group I scores 1 point.

The scores are additive; thus an unpolluted stream will have a Biological Score of 6. If only pollution-tolerant forms are found, the score will be 1. If no organisms are found, the score will be zero. Furthermore, a score of, 1 or 2 points could be allotted to Group III when less than the normal complement is present. Group II could be treated in a similar manner. This scoring device correlated well with the biological oxygen demand, dissolved oxygen, and solids content of the receiving water. Beak also related his scoring device to the fisheries potential. This relationship is shown in Table 4]

TABLE 4

TENTATIVE RELATIONSHIP OF THE BIOLOGICAL SCORE TO THE FISHERIES POTENTIAL (after Beak, 1964) (30)

Pollution status	Biotic index	Fisheries potential
Unpolluted	6	All normal fisheries for type of water well developed
Slight to moderate pollution	5 or 4	Most sensitive fish species reduced in numbers or missing
Moderate pollution	3	Only coarse fisheries maintained
Moderate to heavy pollution	2	If fish present, only those with high toleration of pollution
Heavy pollution	1	Very little, if any, fishery
Severe pollution, usually toxic	0	No fish

4 It has long been known that ecologically severe habitats contain fewer species than normal habitats and that the few species that can survive the severe conditions are often very abundant as they lack competitors. Examples of this are the countless millions of Artemia and Ephydra in saline lakes and the Tubifex tubifex in foul mud. This idea has often been expressed in terms of diversity, which is some measure of numbers of species divided by number of specimens collected. Clearly, such a parameter is larger the greater the diversity, and hence the normality of the habitat. Unfortunately, though as the number of species in any habitat is fixed, it also decreases as sample size increases so no index of diversity has any absolute value (Hairston 1959). If a definite sample size is fixed, however, in respect to numbers of organisms identified, it is possible to arrive at a constant index.

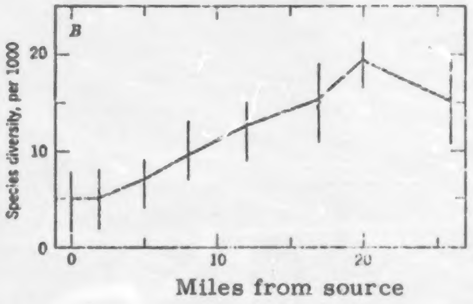

Figure 3. Zooplankton species diversity per thousand individuals encountered in marine systems affected by waste waters from petrochemical industrial wastes. The vertical lines indicate seasonal variations. (30)

5 Patrick et al. (1954) in effect used this concept in a study of diatom species growing on slides suspended in water for fixed periods. They identified 8000 specimens per sample and plotted the results as number of species per interval against number of specimens per species on a logarithmic scale. This method of plotting gives a truncated normal curve for a wide variety of biotic communities. In an ordinarily diverse habitat the mode is high and the curve short; i.e., many species occur in small numbers and none is very abundant. In a severe habitat the mode is low and the curve long; i.e., there are few rare species and a few with large numbers. This, again, seems to me to be an elaborate way of presenting data and to involve a lot of unnecessary arithmetic.

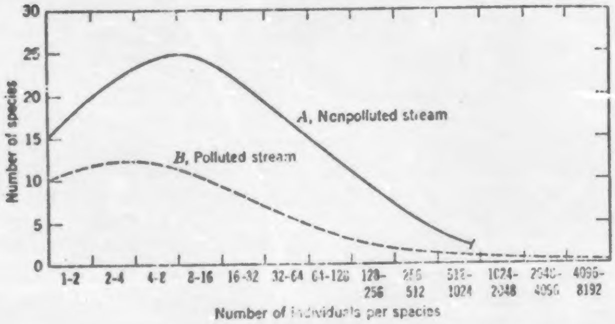

Figure 4. A graphic comparison of diatom communities from two different environments. (After Patrick et al., 1954) (30)

6 Diversity indices vs tabulated data

Allanson (1961) has applied this method to the invertebrate faunas of streams in South Africa and has shown, as has Patrick for diatoms, that the log normal curve is flatter and longer for polluted stations; the difference, however, is not so apparent that it does not need exposition. Here, again, I would suggest that tabulated data are just as informative. Indeed I would go further and say that tabulated data are essential in the present state of our knowledge. We are learning as we go along and if the details of the basic findings are concealed by some sort of arithmetical manipulation they cannot be re-interpreted in the light of later knowledge, nor are they preserved in the store of human knowledge. This point becomes particularly clear when one examines some of the early studies that include tables. Butcher (1946) requotes a considerable amount of data he collected from studies of various English rivers during the thirties; they are not only clear and easy to follow, but they are also informative about the generalities of pollution in a way that data quoted only within the confines of some particular system are not.

7 Examples of tabulated data(Table 5)

Simple tabulation of biological data in relation to water quality, either in terms of number of organisms, percentage composition of the biota, some arbitrary abundance scale, or as histograms, has been effectively practiced in many parts of the world: in America (Gaufin and Tarzwell 1952, Gaufin 1958), Africa (Harrison 1958 and 1960, Hynes and Williams 1962), Europe (Albrecht 1954, Kaiser 1951, Hynes 1961, Hynes and Roberts 1962), and New Zealand (Hirsch 1958) to cite a few. These tabulated data are easy to follow, are informative to the expert reader, and conceal no facts. Although the non-biologist may find them tedious, he need only read the explanatory paragraphs. It is a delusion to think that it is possible to reduce biological data to simple numerical levels. At best, these can only be produced for limited situations and

TABLE 5

	1			2			3		
	206.1 power line			205.1			201.1		
ORGANISMS	left	mid	right	left	mid	right	left	mid	right
Zoothamnium	F								
Dendrocoma	C								F
Spongilla fragilis								A	
Trochospongilla leidyi	C			C					
Unidentified Sponge					F			A	
Cordylophora lacustris		F		F	A	A			
Dugesia tigrina	5		8	4	4	6	14		19
Urnatella gracilis	C	C	C	C	F		F		F
Paludicella articulata	C			F	F	F	F		F
Fredericella sultana	C								
Pristina							1		
Nais communis				1		1		7	
Paranais									
Unidentified Leech									1
Unidentified Beetle			1						
Chaoborus punctipennis					1				
Hydrobaenus sp. A	31	47	5	9	117	68	1	26	4
Cricotopus bicinctus						1			
Unidentified Tendipedini								1	
Harnischia sp. A		5	2		29	2	1	8	
Tendipes nervosus	1				4	15		2	1
Tendipes modestus	99	14	16	7	12	7	1		3
Polypedilum sp. B									1
Calopsectra exigua			2	5	3	48	3	169	101
Trycorythodes	1			1			1		1
Stenonema				1					
Agraylea			2				1		
Athripsodes				2					
Potamyia flava				41		44	19	131	234
Hydropsyche orris				141		17	2	3	11
Cheumatopsyche		1		4	5	43		30	13
Psychomyiidae Genus A	51	22	21	30	54	92	11	193	21
Lithasia verrucosa									1
Ferrissia shimekii				4		33	7	5	19
Quadrula sp.						1	1		
Quadrula tuberculata						2			
Corbicula fluminea	4	1	5	11		1	77		7
TOTAL	152	90	56	261	229	381	141	575	437
	298			871			1,153		

F - few C - common A - abundant

Benthos from Pickwick Tailwater (35)

even then they need verbal exposition; at worst, they give a spurious impression of having absolute validity.

8 Comparison of stations

My final point in this section concerns comparisons. It is claimed that the German system, in effect, measures an absolute state, a definite level of water quality. We have seen that this is not a tenable claim. In the other systems, by and large, the need to establish local control stations at which to measure the normal or "natural" biotic conditions is accepted, and then other areas are compared with this supposed norm. This is, of course not always possible as there may remain no unaffected area, or no unaffected area that is, with respect to such factors as current, nature of substratum, etc., sufficiently similar to act as a base-line for data. Nevertheless, basically, these systems can be used to compare stations and thus to assess changes in water quality. In doing this, they can all be used more or less successfully, but I maintain that a table is just as useful as an elaborate analysis, and I believe that the table should be included with whatever is done. For a particular situation, however, it is often possible to distill the data into a single figure as a measure of similarity between stations.

9 Coefficients of similarity

Burlington (1962) and Dean and Burlington (1963) have recently proposed an entirely objective means of doing this, which involves simple arithmetical manipulation. In his system, a "prominence value" is calculated for each species at each station. This is a product of its density and some function of its frequency in samples, but the details of this calculation can be altered to suit any particular situation. Then a coefficient of similarity between each pair of stations can be calculated by dividing twice the sum of the lower prominence values of taxa that the two stations have in common by the sum of all the prominence values of both stations. Identical stations will then have a coefficient of similarity of 1:00; this coefficient will be lower the more the stations differ from one another. This is an easy way to compare stations in an entirely unbiased way and as such may satisfy the need for numerical exposition; however, it tells one nothing about why the localities are different and like all the other more or less numerical methods of presenting data has no absolute value. Moreover, it still leaves unanswered the fundamental question of how different is "different?"

TABLE 6

Clean

WATER QUALITY (high multiple use indicated)

Organisms in Order of Tendency to Disappear as Degree of Pollution Increases

Types of Organisms Present	BIOTIC INDEX[1] Variety Present	✓Total Number of Groups Present				
		0-1	2-5	6-10	11-15	16+
Plecoptera nymph present	More than one species	--	Bio 7	Index 8	9	10
	One species only	--	6	7	8	9
Ephemeroptera nymph present	More than one species *	--	6	7	8	9✱
	One species only *	--	5	6	7	8
Trichoptera larvae present	More than one species •	--	5	6	7	8
	One species only •	4	4	5	6	7
Gammaridae present	All above species absent	3	4	5	6	7
Asellus and/or *Lirceus* present	All above species absent	2	3	4	5	6
Tubificid worms, *Tendipes*, and *Cricotopus bicinctus* (one or more of these groups)	All above species absent	1	2	3	4	--
All above types absent	Some organisms such as *Eristalis tenax* not requiring dissolved oxygen may be present	0	1	2	--	--

Polluted

* *Stenonema nepotellum* excluded   10✱ main stream reservoirs and west Tennessee streams

• *Stenonema nepotellum* (Ephem.) is counted in this section for the purpose of classification.

✓ ONE FOR EACH KNOWN SPECIES IN THESE GROUPS:

- Platyhelminthes
- Hirudinea
- Mollusca
- Crustacea
- Plecoptera
- Diptera (excluding specific ones listed below)
- Coleoptera
- Neuroptera

✓ ONE FOR EACH GROUP, REGARDLESS OF NUMBER OF SPECIES, ETC.:

- Annelida excluding Naididae
- Naididae
- Each Mayfly genera (excluding *Stenonema nepotellum*)
- *Stenonema nepotellum*
- Each Trichoptera family
- Chironomidae (excluding specific ones listed below)
- *Chironomus riparius* and *plumosus* and *Cricotopus bicinctus*.
- Family Simuliidae

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[1] adapted from Trent River Board - Tennessee Stream Pollution Control Board 8/66 RMS

IV THE PROBLEMS OF SAMPLING

The systems outlined above are all based on the assumption that it is possible to sample an aquatic habitat with some degree of accuracy; this is a dubious assumption, however, when applied to biological data. From what has been said about the complexity of biological reactions to the various factors in the environment, and from the obvious fact that rivers especially are a mosaic of microhabitats, it is clear that to achieve numerical accuracy or even some limits of confidence considerable numbers of samples need to be taken. Indeed, even in so apparently unvaried a habitat as a single riffle, Needham and Usinger (1956) showed that a very large number of samples would be necessary to give significant numerical data.

A Representative Sampling

There is a limit to the number of samples that can reasonably be taken and, anyway, it is desirable to sample many different types of habitat so as to get as broad as possible an estimate of the biota. This is the more recent approach of most of the workers in Central Europe, who have been content to cite abundances on a simple relative but arbitrary scale and to convert this to figures on some sort of logarithmic scale for use in calculations. An alternative is to express the catch in terms of percentage composition, but this had the disadvantage that micro- and macro-organisms cannot be expressed on the same scale as they are obtained by different collecting techniques. Also, of course, implicit in this approach is the assumption that the sampling is reasonably representative. Here again we run into the need for knowledge and expertise. In collection as well as in interpretation, the expert is essential. Biological sampling, unlike the simple, or fairly simple, filling of bottles for chemical analysis or the monitoring of measuring equipment, is a highly skilled job and not one to be handed over to a couple of vacationing undergraduates who are sent out with a Surber sampler and told to get on with it. This point has also been made by other biologists, e.g., Patrick (1961) who stresses the need for skilled and thorough collecting even for the determination of a species list.

B Non-Taxonomic Techniques

Alternatively we can use the less expert man when concentrating on only part of the habitat, using, say, microscopical slides suspended in the water to study algal growth. This method was extensively used by Butcher (1946), and Patrick et al. (1954) who studied diatoms in this way. This gives only a partial biological picture, but is useful as a means of monitoring a stretch of water where it is possible that changes might occur. It is a useful short-hand method, and as such is perhaps comparable to studying the oxygen absorbed from potassium permanganate instead of carrying out all the usual chemical analyses on water. A short method of this kind may serve very well most of the time, but, for instance, would not be likely to detect an insecticide in concentrations that could entirely eliminate arthropods and hence fishes by starvation.

C Monitoring

It is possible to work out biological monitoring systems for any specific purpose. The simplest of these is the cage of fish, which, like a single type of chemical analysis, can be expected to monitor only one thing — the ability of fish to live in the water — with no information on whether they can breed or whether there is anything for them to eat. Beak et al. (1959) describes a neat way in which the common constituents of the bottom fauna of Lake Ontario can be used to monitor the effluents from an industrial site. Obviously there is much room for such ingenuity in devising biological systems for particular conditions, but this is perhaps outside the scope of this meeting.

V CONCLUSIONS

It may appear from the previous sections that my attitude to this problem is entirely obstructionist. This is far from being so. Water quality is as much biological phenomenon as it is a chemical or physical one; often what we want to know about water is almost exclusively biological -- will it smell nasty, is it fit to drink, can one bathe in it, etc? I suggest, therefore, that it is desirable to organize water monitoring programs that will tell one what one wants to know. There is no point in measuring everything biological, just as there is no point in performing every possible chemical analysis; what is measured should be related to local conditions. It would be a waste of time to measure oxygen content in a clean mountain stream; we know it to be high, and it becomes worth measuring only if we suspect that it may have been lowered by pollution. Similarly, there is little point in studying the plankton in such a stream; we know it only reflects the benthic flora. In a lake or in a slow river, on the other hand, if our interest in the water lies in its potability, records of the plankton are of considerable importance as changes in plankton are, in fact, changes in the usability of the water.

A Periphyton and Benthos Studies

For long-term studies, especially for the recording of trends or changes induced by pollution, altered drainage, agricultural poisons, and other havoc wrought by man, one can expect informative results from two principal techniques: First, we can study microscopic plant and animal growth with glass slides placed in the water for fixed periods; second, we can obtain random samples of the benthic fauna. The algae and associated microfauna tell one a good deal about the nutrient condition of the water and the changes that occur in it, and the larger benthic fauna reveal changes in the trophic status, siltation due to soil erosion, effects of insecticides and other poisons, etc.

B Varying Levels of Complexity

The study of growths on glass slides is reasonably skilled work, but can easily be taught to technicians; like chemical monitoring, such study needs to be done fairly often. Sampling the benthos is more difficult and, as explained above, needs expert handling; unlike most other monitoring programs, however, it need be done only infrequently, say, once or twice a year. Inevitably sampling methods will vary with type of habitat; in each case, the question will arise as to whether it is worth looking at the fish also. It is here that the biologist must exercise judgment in devising and carrying out the sampling program.

C Data Interpretation

Judgment is also needed in the interpretation of the data. It is for this reason I maintain that it should all be tabulated so that it remains available for reassessment or comparison with later surveys. If need be, some sort of numerical format can be prepared from the data for ad hoc uses, but it should never become a substitute for tabulations. Only in this way can we go on building up our knowledge. Perhaps some day we shall be able to pass all this information into a computer, which will then be able to exercise better judgment than the biologist. I hope this will happen, as computers are better able to remember and to cope with complexity than men. It will not, however, pension off the biologist. He will still be needed to collect and identify the samples. I cannot imagine any computer wading about on rocky riffles nor persuading outboard motors and mechanical grabs to operate from the unstable confines of small boats. We shall still need flesh and blood biologists long after the advent of the hardware water chemist, even though, with reference to my earlier analogy, a Tokyo University computer recently outpointed 10 veteran medicals in diagnosing brain tumors and heart disease. It should be pointed out, however, that the computer still had to be fed with information, so we are still a long way from the hardware general practitioner. I believe though that he is likely to evolve before the hardware biologist; after all, he studies only one animal.

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Reprinted from: Symposium Environmental Measurements Valid Data and Logical Interpretation, July 1964, PHS Publication No. 999-AP-15, pp. 289-298.

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Descriptors: Aquatic Life, Benthos, Water Quality, Environmental Effects, Biological Indices

THE PHYSICAL AND BIOLOGICAL COMPONENTS OF THE ESTUARINE ECOSYSTEM AND THEIR ANALYSIS

I THE BIOTIC COMPONENT OF THE ESTUARINE ECOSYSTEM

A The Problem of Taxonomy

1 Necessity of identifying species

Studies of the ecology of any habitat require the identification of the organisms found in it. One cannot come up with definitive evaluations of stress on the biota of an estuary unless we can say what species constitute the biota. Species vary in their responses to the impact of the environment.

2 Solutions to the problem

a Evasion

Treat the ecosystem as a "black box" -- a unit -- while ignoring the constitution of the system. This may produce some broad generalizations and will certainly yield more questions than answers.

b Compromise

Work only with those taxonomic categories with which one has the competence to deal. Describe the biotic component as a taxocenosis limited to one or two numerically dominant taxonomic categories, bearing in mind that numerically taxa which are ignored may be very important to the ecology of the estuary.

c Comprehensive description

Attempt a comprehensive description of the biota. No one can claim competence to deal with more than one or two groups. The cooperation of experts must be obtained. The Smithsonian Institution has a clearinghouse for this sort of thing[1]. Lists of expert taxonomists can be obtained (2 a, b, c) (3). There will be none for some groups. Also collaboration is time consuming.

B Environmental Classification of Biota

1 Plankton

All motile aquatic organisms, plant or animal, whose powers of locomotion are too feeble to resist the set and drift of currents are classified as plankton.[4]

a Phytoplankton

The term phytoplankton is usually applied to acellular (unicellular) floating plants but strict adherence to the foregoing definition should include all floating cellular plants such as Sargassum. Representative phytoplankters are shown in Figure 1.

b Zooplankton

The animal plankters are zooplankton. Some kinds of plankton organisms are equivocal in their conforming to the requirements for classification as plants or animals. Typical zooplankters such as may be found in estuaries are shown in Figure 2.

c Holoplankton

Organisms which are classified as plankton at all stages of their life cycles are called holoplankton. The term is applied both to phytoplankton and zooplankton species which conform to this definition. All of the species shown in Figures 1 and 2 are holoplankters.

d Meroplankton

Planktonic reproductive stages of species which in other stages of the life cycle live on the bottom or are strong swimmers are called meroplankton. These are eggs, larvae, swarming stages, juveniles, or sexual alternates to vegetative stages of a host of marine plants and animals. Typical meroplankters are shown in Figure 3.

e Tychoplankton

Small, weakly motile, bottom-dwelling organisms which are accidentally swept into suspension by turbulent water motion are called tychoplankton. It is easy to see that many of the planktonic species in turbulent estuaries are likely to be tychoplankters.

2 Nekton[5]

Organisms which remain suspended in the water and whose powers of locomotion are great enough to resist the set and drift of currents are called nekton. Only three major taxonomic categories are represented in this classification--the fishes, the cephalopod molluscs (octopuses and squids) and certain crustaceans (shrimps and swimming crabs). Many of these, because of strong affinities for the bottom, may just as easily fit in the benthos (See c). Typical estuarine nekton are shown in Figure 4. Bottom dwelling or reproducing nekton species are called dermersal. Those which live and reproduce suspended in the water are called pelagic.

3 Benthos

Organism which as adults or in the sessile stages of their life-cycles, live on the bottom are called benthos, as, of course, are all whose entire life cycle is spent there. The benthos may also be subdivided.

a Epiflora

Plants, cellular or acellular, macro- or micro-, which live attached to or living on the bottom are called epiflora.

b Epifauna

Animals which live on the bottom are called epifauna. Many representatives of the epifauna are permanently attached to the bottom, a phenomenon which does not occur in the terrestrial environment. Many of these are colonial, which is to say, consist of groups of individuals incompletely separated from one another, like Siamese twins. A result is the evolution of life-forms which are more like conventional plants in appearance than like animals. Other epifauna creep about on the bottom. Figure 5 shows typical epifauna and flora.

c Infauna

Animals which live buried in unconsolidated sediments or in burrows in solid substrates are called infauna. Fixed infauna are those which live in permanent burrows while burrowing infauna move about displacing sediment as they go or by creeping or swimming between the sand grains. If they progress by displacing sediment particles, they are called megafauna. If they are adapted to creeping in the interstitial spaces, they are called meiofauna. Organisms which are so small that they can float or swim in the interestitial spaces are called microfauna.

d Inflora

Macroscopic plants are uncommon on bottoms consisting of unconsolidated sediments. The big exception to this rule are the sea "grasses." Microscopic plants are abundant either fixed to sand grains or lying about on or between them. Bacteria are abundant on all bottom surfaces and in the spaces between sediment grains. A variety of mega-infauna are shown in Figure 6, while Figure 7 shows a number of meio- and micro infauna and inflora.

C Ecological Classification of the Biota

Classification of any sort is a matter of convenience to enable us to pigeon-hole items with which we deal. Ecologists have found it convenient and useful to be able to pigeon-hole aquatic organisms - particularly those of estuaries where normal environmental conditions vary greatly, both spatially and temporally--according to the tolerances of those organisms to ranges of variations in environmental properties. Thus we have, as an example, a classification of estuarine organisms based on tolerance to salinity changes.

1 Salinity Tolerance[6,7]

As mentioned elsewhere salinity in a true estuary ranges from that of freshwater at the head to that of seawater at the mouth. Few organisms are tolerant of this entire range. Salinity tolerance limits are imposed by a species ability to compensate for osmotic stress imposed by variation in the salt content of its environment.

a Limnetic

Limnetic species are freshwater ones characteristic of the river which empties into the head of the estuary. They can tolerate salt content up to 0.5 parts per thousand.

b Oligohaline

Oligohaline species are those derived from freshwater but which have become adapted to living in the head of the estuary where salinity ranged from 0.5 to 5.0 parts per thousand.

c True estuarine

Truly estuarine species are those which can survive in waters ranging from 5.0 to 30.0 parts salinity per thousand. These may be species whose tolerance is purely passive, which is to say, not based on resisting osmotic stress, or species which do possess mechanisms for osmo-regulation. They are species which are really typical of estuaries being unable to tolerate salinities as low as those of the head of the estuary or those of the sea itself. The oyster, Crassostrea virginica is a good example. Some prawns of the genus Palaemonetes are also truly estuarine.

d Marine euryhaline

The great majority of estuarine species are marine species tolerant of salinities ranging from 5.0% to those characteristic of the open sea. Passively euryhaline species are those which tolerate fluctuations in salinity without being able to actively adjust. In dilute waters they swell or lose salt; in more saline waters they shrink or passively accumulate salt. Many molluscs and worms are passively euryhaline. Actively euryhaline species are able to control the salt concentrations of their body fluids despite osmotic stress imposed by variation in environmental salinity. This is characteristic of many polychaetes, most estuarine fishes, and many crabs.

e Marine stenohaline

Species adapted to living at the mouth of the estuary where salinities range from 25‰ to those of the open sea are called marine stenohaline. Most echinoderms which one finds at the mouth of estuaries are stenohaline. The gribble, a tiny crustacean which destroys dock pilings is stenohaline. Many of the common oyster's worst enemies are stenohaline.

f Mixohaline

The few species which tolerate the full range running from freshwater to the sea are called mixohaline. The blue crab, Callinectes sapidus is a notable example of this as well as all the migrants such as the sturgeons, salmon, striped bass, and river herrings which pass through the entire range on their annual reproductive journeys.

2 Temperature tolerance

In estuaries, where environmental temperatures vary much more widely than in the sea, organisms may also be classified according to temperature tolerance in the same manner. Thus we have oligothermal, eurythermal, and stenothermal species.

II ESTUARINE HABITATS

A habitat is the kind of place in which one normally expects to find a given kind of organism. It may be supposed that, because of the wide variety of assemblages of physical conditions and biotic communities, estuaries contain a number of distinct habitats which will be roughly proportional to the variety of conditions.

A Geomorphological Classification of Estuaries[8, 9]

1 Positive estuaries

Positive estuaries are those in which the influx of freshwater measurably exceeds evaporation, producing the gradient referred to in the preceding section.

a Drowned river valleys

Many of the estuaries on the East Coast of the United States fall into this category. Chesapeake Bay is our largest American East Coast drowned river valley.

b Fjords

Fjords are canyons formerly filled and carved out by mountain glaciers. They, too, are drowned by rise of sea level although their bottoms may never have been above sea level. Fjords are found on the Coasts of Norway, Greenland, British Columbia, Chile, and elsewhere.

c Bar-built estuaries

Bar-built estuaries are drowned river valleys or points of egress of freshwater to the sea which have been partly blocked off by the build-up of barrier islands or spits. The North Carolina Sounds and the Texas lagoons are examples of bar-built estuaries.

d Fault or graben produced estuaries

Where differential lowering of the land occurs along the coast in tectonically active regions, estuaries are formed. Tomales Bay north of San Francisco, which is situated in the San Andreas fault zone is such an estuary. San Francisco Bay is another. The Gulf of California and the Red Sea are similarly formed, but of these only the former could be called an estuary.

2 Neutral estuaries

Neutral estuaries are those in which evaporation more or less equals inflow of freshwater, so salinities remain essentially the same as that of the adjacent seawater. Alligator Harbor, near here, is such as estuary.

3 Negative estuaries

Negative estuaries are those in which evaporation so much exceeds fresh or seawater influx that salinities exceed those of the adjacent sea. The upper reaches of the Laguna Madre of the Texas Coast is a hypersaline lagoon or negative estuary.

B Classification of Estuarine Environments[6, 10]

Many authors have proposed subdivisions of the sea into environmental categories. These have been summarized by Hedgpeth.[10] In estuaries we have

1 Pelagic - environmental subdivisions of the water in estuaries, inhabited by plankton and nekton.

a Neritic - the water overlying the edges of the sea from a depth of about 100 fathoms to the shore. The watery environment of all estuaries except the deeper parts of some fjords and tectonically produced estuaries is neritic.

b Oceanic - seawater which is more than 100 fathoms deep in oceans by definition.

2 Benthic - environmental subdivisions of the bottom of the sea including its farthest landward influence.

a Supralittoral

This is a zone between the truly marine and the truly terrestrial (or freshwater) invaded by seawater only when storm surges push the rising tide higher than predicted. Easy to define on open coasts, it is not easily detectable on the bottoms of estuaries. The supralittoral is, however, clearly defined in the small beaches, rocky headlands and manmade structures and the salt marshes which border estuaries.

b Littoral

The littoral is the intertidal. It is the bottom which is alternately covered and exposed by the spring tides if not by the neaps. Large areas of the shores and bottoms of shallow estuaries fall in the littoral. In estuaries characterized by little turbulence, the rising tide enters the main channel as an underlying wedge of dense saltwater, pushing the lighter, freshwater up. There is therefore a very interesting but hard to detect intertidal zone which is never exposed to air.

c Sublittoral

The sublittoral, by definition, extends from the lowest low water marks to the depth of 100 fathoms. It is that portion of the estuary which is always covered by seawater. Obviously, there is also a special estuarine portion of the bottom which is covered by seawater diluted as a result of turbulent mixing with freshwater coming in from the other end.

C Estuarine Habitats[9]

1 Pelagic

Because of the salinity gradient that develops in a positive estuary characterized by reasonable mixing, there develops also a series of pelagic habitats which are more easily detected by the presence of typical organisms than by other properties.

a Head

This is the low salinity habitat of 0.5 to 5.0% occupied by the oligohaline species.

b Upper, middle and lower reaches

These are zones with salinities ranging from 5 to 18, 18 to 25, and 25 to 30% . Not all truly estuarine species nor all marine euryhaline species are found throughout the entire range. Many will be restricted to, or find best growth in one of these reaches.

c Mouth

This is the zone with marine salinities ranging from 30 to 40% , and will be inhabited by euryhaline as well as stenohaline marine species.

2 Benthic

a Supralittoral

As noted, rocks and other hard surfaces (like bulkheads, dock pilings, etc.), marshes and beaches will have a zone of transition between the truly marine and the truly terrestrial which is wet only by splash or storm surges.

b Littoral and sublittoral

1) Beaches

Beaches normally are associated with the open coast as they are dependent for their existence on wave action and longshore currents. But the shores of large estuaries may have small beaches which have the same physical and biotic properties as open coast beaches. Because of constantly shifting sand, this is a very limiting habitat for soft bodied megafauna but a safe haven for meio and microfauna.

2) Rocky intertidal

Especially in estuaries, the rocky intertidal (and other hard surfaces) will be characterized by a great diversity of organisms which occur in zones depending on their ability to withstand prolonged periods of exposure to the atmosphere.

3) Sand flats and shoals

Found in the middle and lower reaches and mouth of the estuary, sand flats and shoals which owe their existence to tidal currents without the wave action which makes beaches are habitats for a tremendous diversity of epiflora and fauna and of infauna. The greater stability of the sediment permits the existence there of rooted plants and many kinds of megafauna.

4) Mud flats

In the upper reaches and other places protected from currents and waves, mud flats develop. With a very high organic content, anaerobic conditions prevail below the top two or three millimeters except where oxygenated water is entrained by burrowing organisms. The surface is characterized by intense biological activity.

5) Oyster bars

In positive estuaries where sedimentation precludes establishment of oyster colonies in the zones of estuarine salinity, oysters can grow only near the mouth where salinity is high enough to support oyster predators. The oysters then thrive only in the intertidal and produce large reefs exposed by the falling tide.

6) Mangroves

Along the shores of tropical estuaries great thickets of mangroves provide a peculiar type of intertidal and subtidal habitat. The prop roots of the red mangrove provide substrate for many benthic species and shelter for many pelagic ones.

7) Submarine meadows

The bottoms of many estuaries are covered with extensive growths of marine "grasses" which are seagoing relatives of some of our pond weeds. They provide a habitat for a greater assemblage of species than any other marine habitat except the coral reef.

8) Mussel and barnacle beds

On firm, peaty intertidal bottoms of temperate and boreal estuaries extensive beds of the blue mussel and of barnacles form a special kind of habitat.

9) Salt marshes

On the sides and shores of the upper, middle and lower reaches of drowned river valleys and on the shores of bar built estuaries, salt marshes will be found. Dominated by a single species of grass, but inhabited by a very limited variety of animals, they vie in productivity with Iowa cornfields, nourishing not only their inhabitants but also many organisms in the adjacent lower portions of the estuaries.

10) The interstitial

The interstitial habitat is the space between the grains of sediment occupied by the meio- and micro-infauna. Dependent on turbulence for percolation of oxygenated water it has a greater diversity of organisms on and near beaches.

III THE ESTUARINE ECOSYSTEM[12]

The term ecosystem implies that not only is a particular habitat required by a particular assemblage of organisms but also that the assemblage or community modifies and to a certain extent creates the habitat. The root of the term is perhaps best defined by Watt[11] who says that, "A system is an interlocking complex of processes characterized by many reciprocal cause-effect pathways." The interactions between the biota and the physical properties and among themselves are the processes. Ecosystems vary in size. Theoretically, at least, each could flourish with an input of energy only.

A The Physical Components

1 Substrate

The substrate is that portion of the physical environment on or within which organisms live. It is the ground, the sediment, the rock or other surface. It provides purchase, food, shelter, or attachment.

2 Medium

The medium is the fluid which bathes the organisms. For us it is the atmosphere. For estuarine organisms (except when the tide is out) it is the water. It is the medium through and with which individuals exchange matter and energy.

3 Energy sources

Every ecosystem must have a primary energy source. For terrestrial ecosystems it is ultimately the sun. For small circumscribed systems on earth, the energy input comes as chemical energy. From most ecosystems most of the input energy is lost as heat in a very short time--all of it ultimately.

B The Biological Component--The Community

1 Definition

A biological community is an assemblage of interacting populations of species, all more or less dependent upon each other for their individual and collective survival.

2 Mega- and micro- communities

The biota of an entire estuary, sea, or ocean may be considered a community, just as may be the biota found on a single blade of turtle grass. The essential thing is that the assemblage is so integrated that by mutual support and dependence its constituents could survive without outside input other than energy in some form.

3 Community succession

a Spatial

Just as the gradient of water properties extends from head to mouth of the estuary, so also may be found a succession of different bottom types inhabited by distinct and recognizable assemblages of species. This is spatial succession.

b Temporal

At any one point or station in the estuary, a succession of different assemblages of species may be found with the passage of time. This is particularly true of pelagic species and epifaunal and epifloral organisms and on a seasonal basis. This is temporal succession.

IV ECOSYSTEM DYNAMICS[13, 14]

A Energy Flow and the Cycling of Matter

The essential attribute of ecosystems is change, the result of the constant cycling and recycling of matter accompanied by the degradation and one way passage of energy. Energy enters the system from without and quantitatively passes out of it, after delays ranging from fractions of seconds to millions of years. Matter keeps being recycled as a means of capturing and transferring energy. The estuarine ecosystems are not exceptions.

1 Trophic structure of the community

The biotic component is the principal and certainly the most efficient captor and utilizer of energy. It takes energy as it comes to the ecosystem, in the form of light, converts it to a usable form--the energy of chemical bonds and in so doing makes more life. Its units grow and reproduce. The energy bearing matter changes hands repeatedly. All the while greater or lesser portions of the energy are lost as heat which ultimately is radiated on out (resuming its original journey from the sun) into space as infrared radiation from the dark side of the earth. In each community there are discernible levels between which matter and energy are exchanged.

a Trophic levels

The initial trophic (processor of energy-bearing matter) level is that of the primary producer. Most of these are photosynthetic plants which make new living matter (complex chemical energy-bearing organic compounds) from nonliving matter (simple inorganic compounds) the extra energy required for this coming in the form of light.

Primary consumers are vegetarian animals which (pardon the redundancy) eat plants. They do this because they are dependent for energy entirely on that of chemical bonds, except for what energy they can pick up by sun-bathing. They cannot use light for essential life processes. This is true of all other consumers as well.

Secondary consumers are the meat eaters or carnivores which eat herbivores or other carnivores.

Decomposers are the molds and bacteria which break down organic substances into the inorganic which the primary producers used in the first place. This is not to say that the producers and consumers do not do this too, but the ultimate dissolution of organic to inorganic is performed by the decomposers.

Primary producers are also called autotrophs.

All the others are called heterotrophs, except that some people apply a special term--saprotroph--to the decomposers.

b Food chains and food webs

Because particular consumer species become adapted to consuming particular primary producers and they in turn are peculiarly esteemed as articles of diet by especial species of carnivores, there appear in communities more or less obligate interdependencies which are called food chains. Because these chains become joined by cross linkages, the trophic structure of the community takes on the appearance of a web of interactions.

2 The Eltonian pyramid and the second law

In most organisms, most of the food consumed is used up maintaining the status quo. Only a fraction appears as a growth or reproductive increment. It therefore requires a far greater gross input from any trophic level to achieve the net at the next above. This step by step reduction in realized living matter is called the Eltonian pyramid. Figure 8 shows a theoretical food web. The three Eltonian pyramids shown in Figure 9 demonstrate the different results obtained when the pyramids are erected on the basis of numbers, biomass as weight, and energy content.

B Population and Community Dynamics[15, 16]

Populations are assemblages of individuals of one species. Communities are assemblages of interacting populations. Both populations and communities have measurable properties peculiar to their respective levels of organization. Such properties may be used to estimate the effect on either of stress in any form.

1 Relevant population properties

a Density

Density is the average or mean number of individuals per unit area or volume of the environment.

b Dispersion

Dispersion is the pattern of spatial distribution of individuals in the habitat. It may be aggregated, random or regular.

c Dispersal

Dispersal is the rate at which individuals of a species population spread through the habitat from a point of entry, either as immigrants or as newly reproduced recruits.

d Growth and age at first maturity

This is the average size and age of the population when the individuals first come into reproductive condition.

e Recruitment

Recruitment is a rate also--the rate at which new individuals are added to the population.

f Mortality vs survival

Mortality is the rate at which individuals are removed from the population, by whatever means. The survival rate is the reciprocal of mortality.

g Frequency

Frequency is the rate at which individuals appear in samples, expressed as a percent. It is the number of individuals divided by the number of sampling units (see below) multiplied by 100.

h Fidelity

Fidelity is a measure of the extent to which one may expect to find a species in a sample of the habitat.

2 Properties of associations of populations[17]

a Population pairs (pairs of species)

1) Affinity is a measure of the extent to which a species is a normal constituent of another's environment.

2) Dominance

Dominance is a measure of the extent to which one of a pair of species dominates the other.

3) Relative abundance

Relative abundance is the number of individuals of a population relative to the numbers of individuals of other populations which have been demonstrated to be significant parts of the first population's environment. As a population property, it is also useful to develop ideas about the structure of the community.

4) Concordance

Concordance is a property of pairs of species. It measures the extent to which they agree that the environment in which they are found is a good one to live in. Much less useful is the simple correlation coefficient.

All these are numerical properties. They are defined in terms of numbers the significance of which can be tested objectively.

b Assemblages of populations - communities

1) Diversity

Diversity is a measure of the complexity of the biotic portion of an ecosystem. The greater the diversity the greater the number of ecological niches, or "occupations," occupied by species populations. The magnitude of diversity of a community is a function of time and the stability of the environment--allowing for the evolution, in situ, of niches and of immigration of species from without. This property, which may also be defined mathematically, is at once a means of identifying the community, and a means of correlating its structure with the stability of the environment.

2) Species - abundance curves

If as one takes successive sample units from the habitat he plots the number of species against the natural logarithm of the number of individuals he gets a curve which is a measure of the density of the community. It has been demonstrated that a break in the curve may be interpreted as invasion by the sampler into the habitat of another community.

3) Homeostasis

Homeostasis is the capacity of a community to survive in the face of unusual stress. It is a function of diversity.

V EVALUATION OF CHANGE IN AN ESTUARY

A Criteria

1 Community composition

If the normal species composition of one or more communities is known, even qualitatively, it may be used as a means of estimating the effects of change in environmental conditions.

a Indicator communities

The identification of peculiar communities with particular assemblages of physical environmental conditions may be used to indicate the development of such environmental conditions as a result of natural or man-made change.

b Indicator species

The same concept set forth in the preceding paragraph may be applied to particular species.

2 Population properties

The numerical properties of populations of species known to be obligate inhabitants of estuaries may be used as more objective evaluations of change resulting from alteration of the environment.

3 Productivity

Productivity is a measure of the rate of production of living matter by a population, a community, or of an entire ecosystem. Although it is not easy to measure, it is an attractive criterion upon which to estimate the economic potential of a habitat, or of any of the constituents as well as the effects upon that potential of alterations in the environment.

a Primary or autotrophic productivity[18, 19]

This is the rate of production of new living matter from inorganic substances chiefly by photosynthesizing plants. As will be recalled from our discussion of trophic levels, we have always to distinguish between gross primary production and net, the difference being the consumption of the product by the producer itself.

b Consumer or heterotrophic productivity[20, 21]

This is the rate of production of living matter by herbivores and carnivores. In species where populations are easy to sample, it is not too difficult to do.

c Productivity of the estuary[22]

From an economic point of view it becomes eminently desirable to be able to estimate the capacity of the estuary, as an ecosystem, or of any part of it, through the activities of its inhabitant species, to yield living matter. Obviously, the description of the estuary as an ecosystem--its physical properties and biotic communities--must be at hand in order to use this criterion.

4 Microbiological assays

If the capacity of the water or of the sediment on the bottom of any or all parts of the estuary to support life and economically desirable productivity is known, then the effects of changes in these constituents of the environment can be evaluated by microbiological assays. This, put simply, means assaying the capacity of water or sediment taken from the estuary to support growth of populations under controlled laboratory conditions.

B Necessity of Continuing Periodic Observations

1 Correlation versus regression

If only spot measurements of physical and biotic properties of the estuary are made, one may be lucky enough to obtain significant correlations, but if periodic measurements are made, not only will correlations be more acceptably significant, but also one may be able to plot regression curves, by which change in biotic properties may be linked with combinations of physical properties and their variations over a period of time.

2 Seasonal effects

An obvious reason for basing evaluation of change in an estuary on observations made periodically over a long period of time is that the normal effects of seasonal climatic change have to be taken into account.

3 Succession[24]

One of the effects of seasonal climatic change is the annual succession of populations and communities of organisms in those parts of the estuary where periodic changes are greatest. One community will arise, prosper and fritter away to be supplanted by another. Other forms of stress bring this about. Catastrophic change, as for example the complete covering of an area of bottom by flood borne silt will establish the basis for the beginning of a new succession. Introduction of hard surfaces into the environment, or hurricane destruction of grass beds or oyster bars will do likewise. Knowledge of normal stages of succession is essential to reliable evaluation of change.

VI THEORETICAL ASPECTS OF SAMPLING

A Necessity of Sampling

1 Excision of sampling units

In order to estimate properties, describe the biota, or whatever, it is in most cases necessary to sample--to remove portions of the habitat to see what's in it. Only rarely can one enumerate items in situ, leaving them untouched by the process.

2 Impracticality of whole counts

Even where it is possible to count individuals in situ in the habitat, it is generally physically and economically impractical, so we have to make do with samples.

B Necessity of Programmed Sampling[25, 26]

1 Accuracy and precision

a In any kind of mensuration, it is eminently desirable to do it accurately. Accuracy is a measure of our confidence that the sampling method we employ is free of error, representative of the population we are sampling or that the methods subsequently employed to analyze the sample will yield acceptably close estimates of the properties of the population we have sampled.

b Precision is a measure of the confidence we have that methods employed once will yield unswervingly reliable estimates. This is to say that we are dependent on precision in order to make comparisons.

C Sampling for Community Composition

1 Systematic sampling

When we are only trying to sample for qualitative data--to determine what kinds of things we find in the habitat--and especially when we have a lot of territory to cover, it is best to lay down a geometrically regularly spaced pattern of stations at which to take sampling units.

a Limitations

Systematic sampling is limited to the making of surveys. It is the method of reconnaisance. It is biased and therefore useless or at least very unreliable for the estimate of quantitative properties of populations.

b Advantages

Systematic sampling is the method of choice when time and money are limited and only qualitative data are required. It is the method of reconnaisance.

c Spatial and temporal systematic sampling

In an estuary spatial systematic sampling may be done at the intersections of a grid or at intervals on transects, or merely at regularly spaced intervals on a midline or even with the center of the main channel running from the head to the mouth. Temporal systematic sampling means taking a sampling unit at regularly spaced intervals in time at the same point in space.

D Sampling for Population or Community Properties

1 Necessity for control of bias

Sampling for numerical properties demands freedom from bias. Bias is a measure of inequality of the chances of individuals being picked up in the sample. Freedom from bias is a measure of the equality of opportunity of every individual being taken in the sample. This is one of the criteria for accuracy.

2 Sampling patterns

a Random sampling

Random sampling may be achieved by laying out a grid, for example, numbering the intersections of the grid in a systematic manner and taking samples at intersections whose numbers are ordered by the sequence found in a table of random numbers or the last two or three digits in a series on any page of the Manhattan telephone book. Random sampling gives maximal freedom from bias. But it is difficult and sometimes uneconomical to do.

b Stratified random sampling

A pattern of sampling which is easier to do and still gives a sample almost as free of bias as a random sample, is stratified random sampling. In this case, for example, one may select regularly spaced areas in a habitat and excise units on a random pattern within each.

3 Sampling unit and sample size

The size of the "chunk" for excise from the habitat as well as the number of chunks influence the representativeness of the sample. If the former is too small in relation to the pattern of spatial distribution of what you are sampling you may get a sample which will suggest clumping even though the species is uniformly distributed. If it is too large you may get an erroneous suggestion of uniform distribution. A way in which both birds can be killed with one stone is to sample what seem to be significant species, using three or four sampling unit sizes. As successive lots of five sampling units are taken, the cumulative mean is plotted on the ordinate against the number of units on the abscissa. For an unrealistically large sampling unit, the curve will be level from the beginning. For an unacceptably small unit the curve will fluctuate wildly and never level off. For an optimally sized unit, the curve will fluctuate (or deviate) on either side of a certain value at which it will level off. The intercept with the abscissa of a line dropped from the point of leveling off gives the optimal number of sampling units, or sample size. The point of leveling off gives as near a representation of the true population mean of the species as possible.

4 Estimates of accuracy

In Section B, 1 above we defined accuracy as a property of method. It may also, of course, be defined as a property of the result. In this case it is a measure of the closeness of an estimate to the true value. Minimizing the variance which is the basis of the method described in the preceding paragraph is a practical way of ensuring a mean which is acceptably accurate. Obviously, the larger the sample, the smaller the average deviation from the mean. This is a practical way of evaluating the accuracy of a determination. Another rule of thumb is not to accept an estimate which is less than 2.5 times its standard deviation.

5 Estimating precision

Precision has been defined as an attribute which is achieved when acceptable accuracy is obtained in a succession of samples of the same population. Estimate of precision may be made by the method of testing to determine the probability that a greater difference between the means of two samples could be obtained. If an acceptable probability is achieved one may assume that the method is precise and that the two samples are drawn from the same population.

VII PRACTICAL PROBLEMS IN ESTIMATING POPULATION OR COMMUNITY PROPERTIES

A Methods of Collecting

1 Plankton[4, 27, 23]

a Nets

Qualitative plankton nets are funnel shaped devices, closely resembling the airport "wind-sock" with a container on the small end. They are made of monofilament nylon cloth of varying mesh sizes. They may be towed horizontally, vertically or obliquely. Even the finest does not catch all the plankton. Quantitative plankton nets are equipped with opening and closing devices and with meters which make possible an estimate of the amount of water which has been strained.

b Pumps

Pumps are preferable to nets because one can be certain that all the water of the sample goes through the net, if that is employed to filter out the plankton. Within the limits imposed by the lowering of hose, one can know the exact depth from which a sample is obtained. The bulkiness of hose is a disadvantage.

c Traps

Plankton traps are devices which cut off a volume of water, isolating the plankton in it. The many kinds of water bottles used by aquatic scientists fall into this category.

2 Nekton[28]

Nekton means fishes as a general rule. Being nekton they must be captured by conventional fishing methods.

a Tagging

A number of methods for estimating population properties of fishes are based on the principle of the effect of the whole population diluting the

185

concentration of marked individuals. A result is the development of a variety of tags with which live fish are marked and returned to the environment.

b Fishing gear

1) Hook and line

2) Mazes

Mazes range from hoop or fyke-nets to huge stationary fish traps.

3) Entangling nets

Typical entangling nets are trammel nets which consist of three nets in one--two outside ones with large meshes and one inside one with small meshes. The fish swim through the large mesh on one side, push the fine mesh through the large mesh on the other and make a pocket from which they cannot escape. Gill nets are made of mesh of such a size that the fishes push their heads through but are stopped by the dimensions of their bodies. Retreat is impossible because their gill opercula hang up.

4) Encircling nets

These are the seines by which fishes are surrounded and hauled out on the beach. Purse seines are constructed so they can be drawn together on the bottom.

5) Towed nets

The most widely used towed net is the oter trawl which is a funnel shaped net whose mouth is kept open by paravanes as they are towed through the water.

) Poison

In circumscribed, small bodies of water fairly accurate whole counts of the fish populations can be made by poisoning the water with rotenone.

c Fishing statistics

1) Annual canvass

This is an annual survey conducted to determine not only how many fishes were caught by commercial operators, but also who went out when and with what kind of gear.

2) Sales slip

In some states and countries, there is required by law, that all who sell fish relay to the Conservation Department one copy of every record of sale.

3) Vessel landings

Fishery statistics may be accumulated by obtaining from middlemen the records of vessel landings.

4) Log books

5) Daily delivery sheets

6) Fixed gear records

These are the records of fish taken out of fish traps and pound nets.

7) Sport fishing records

Valuable fishing statistics can be obtained through angler's organizations and the operators of sport fishing lodges, marinas, boats and the like.

3 Benthos[29]

a Gear

1) Dredges

Dredges are rigid box or net like structures dragged along the bottom clipping off the epifauna or digging in slightly to remove the most superficial infauna.

2) Grabs

Grabs are devices which bite out single chunks of the bottom.

3) Sieve, shovel, tongs, rakes

On bottom which may be reached with tools operated by hand, or on which a person may wade, any of a variety of devices may be used to sample the benthos.

b Fishery statistics

For information concerning benthos populations which are exploited commercially, fishery statistics of the sort outlined in the section on nekton may be useful.

B Processing the Collections

1 Plankton[23]

Plankton caught in conventional nets usually need to be diluted to achieve concentrations which are workable in the small containers used on microscope stages. Plankton caught by pump or in traps usually have to be concentrated.

a Filtration

Small volumes as from water bottles can often be quantitatively filtered on membrane filters, the counts and identifications being made when the membrane is transferred to a slide for microscopic study. The plankton may be stained and the filter cleared with cedar oil or with Karo syrup.

b Sedimentation

As filtration often damages delicate organisms, dilute samples may be allowed to settle out in vessels especially designed for the purpose, the collection then being examined preferably by an inverted microscope.

c Centrifugation

A high speed centrifuge of appropriate design will concentrate all but the tiniest plankton organisms. Because the smaller sizes are lost through the meshes of nets and in centrifuging, filtrations and sedimentations are preferable.

2 Nekton

Fishes need only to be preserved. This requires injections of preservative into the body cavity and exposure to appropriate concentrations of the stuff long enough to insure complete infiltration.

3 Benthos

Most benthic organisms are small and collections taken by dragging or grabbing usually require careful sorting or sieving to separate them from sediment or other trash.

C Determinations of Quantitative Properties

1 Plankton

a Density

Density is given by $\frac{\Sigma x}{N}$ in which x is the number of individuals in each sampling unit and N is the number of sampling units expressed as units of area or volume. The values of x may be determined by:

1) Direct counts of aliquots

Small plankton organisms may be counted on counting chambers of the sort used in blood counts; larger kinds may be counted in Sedgwick-Rafter cells or any other small dish or container which may be scribed or calibrated to facilitate counting.

2) Cultures

The population densities of phytoplankton species may be estimated by such methods as the dilution technique.

3) Estimates of chemical parameters

Determination of the chlorophyll, particulate carbon, "organic" phosphate or carbon of samples may be used to estimate population density.

2 Nekton[28]

a Determination of meristic characters

Meristic characters such as the number of vertebrae, the number and distributions of scales, and certain body proportions of fishes have been shown to be related to environmental influences. The important thing to remember is that one should be quite rigid about making his counts in the same places.

b Age determinations

The age of fishes can be determined by any of a number of means.

1) Scales

The scales of bony fishes have annual rings which may be counted.

2) Otoliths

Otoliths are concretions found in the auditory labyrinth of fishes. The successive layers are laid down annually, so sections of these structures reveal the fish's age.

3) Vertebrae

Similar annual concretions are found in the centra of some fishes' vertebrae.

4) Spines and rays

Annual increments of growth can be detected in the bony spines and rays found in fishes' fins.

5) Tagging

By capturing fishes, tagging them with date-bearing devices and releasing them, recapture gives an accurate determination of age since the date of tagging. If fishes known to be in their first year are so tagged, the age in years is of course known completely.

6) Length - frequency

For many fishes--particularly exploited species which occur in estuaries--the average length achieved at particular ages is known. The frequency with which a certain length appears in a sample can thus serve as an estimate of age.

c Estimates of properties[28, 30, 31]

1) Density

a) Area density

This is the number of individuals per unit area, given, as we have seen above by

$$\frac{\Sigma x}{N} .$$

b) Age frequency

Here one accumulates data on the frequency with which age groups appear in the catch. An age-frequency curve is plotted. From this we get an estimate of mortality--the rate at which individuals are being removed from the population. We then get an estimate of total population density by dividing the total catch by the mortality rate.

c) Capture-mark-recapture

Assuming that tagged fish behave like untagged members of the population in all respects, that loss of tags is proportional in different years, and that there is no variation in fishing activity, population density can be estimated on the basis of dilution of a proportion of tagged fish by the population as a whole. The simplest equation for this method is

$$P = N \times \frac{M}{R}$$

in which P equals the population density, N is the total catch for the season, M is the number of fishes originally marked and released, and R is the number of these which are recaptured. There are more elaborate ways of doing this when the above assumptions break down.

d) Regression

This method is based on the fact that the decrease in the catch per unit effort which results from depletion of the populations, is a function of the extent of the depletion. It is assumed that there is no migration in or out of individuals of the age group in question.

2) Growth and age at first maturity

This property is determined by correlating the length of fishes with the appearance of some structure or state of development of some part of the reproductive system taken to indicate the onset of maturity.

3) Recruitment

Estimates of recruitment depend not only on tabulating the proportions of age-groups in the catch, but also on the catch including the recruits.

4) Mortality versus survival

This, as we have seen, depends on determining the proportions in the total catch of different age groups. A plot of the decrease in numbers of individuals per age group with the passage of time gives a survivorship curve. The reciprocal of this is the mortality.

5) Frequency

Frequency is a statistic which is useful in estimating the status of a population in the community. It is the number of times the species appears in each sampling unit divided by the number of sampling units and multiplied by 100.

6) Fidelity

As we have seen, this is a measure of the consistency with which a species appears in samples. It is a measure of the extent to which a species is restricted to a particular habitat. It may be determined by expressing the difference in frequency of a species in two samples as a proportion of the lesser value. It ranges from 0 to infinity.

3 Benthos

The population properties of benthic species which may be of use in evaluating change in environmental factors are essentially the same as those listed for nekton. There are others, of course.

D Properties of Pairs of Species - Significant Associations

1 Determination of significant associations

a Indices of affinity

One way of estimating affinity is with the 2 × 2 contingency table which will give the expected frequency with which you will get sampling units with A alone, B alone, A and B, and neither. Comparison of the expected with the observed is done and an appropriate test for the probability that you will get a greater difference, or the probability that the difference is due to more than chance gives you an index of affinity. There are others.[34]

b Correlation coefficient

A positive correlation coefficient, the formula for which can be found in any good statistics text, gives an estimate of the necessity for A being a part of B's environment or vice versa. A negative coefficient shows the extent to which one is bad for the other.

c Rank correlation coefficient

This is easier to do. It is also a means of estimating whether one species benefits by the presence of the other or is harmed by it. The procedure can best be obtained by going to the original source.[32]

E Properties of Assemblages of Populations--Communities

1 Properties based on relative abundance

a Dominance

As suggested by Sanders[33], this may be computed by first ordering the species in each sampling unit in terms of the number of individuals. The individuals are then summed in order starting with the most abundant species. Those species which have been included in the summation when it reaches the value of half the total number of individuals present in the unit are the numerical dominants of the unit. The frequency of this dominance is an important estimate of the significance of the species' presence in the community. Other ways of computing dominance are offered by Fager.[17, 34]

b Concordance

As already stated, concordance is an estimate of the extent of agreement between species as to whether or not the habitat in which they are found is a good one in which to live. The method by which it is computed is given by Kendall[32]. While not particularly difficult, it is a bit too elaborate for inclusion here.

2 Properties based on affinity and diversity

a Affinity

One of the most effective ways in which to determine from distributional data what species found in a sample are significant members of the community is Fager's[34] determination of recurrent groups. This is based on the 2 × 2 contingency type of index of affinity. It is not too difficult and is invariably repeatable by any succession of persons who follow the rules.

b Diversity

A number of indices of diversity which are used as a means of distinguishing between communities have been devised. An index based on the relationship of the number of species to the logarithm of the area from which they were collected was proposed by Gleason.[35] Derivatives of this have been proposed by others. Sanders[36] has also developed an index of diversity which cannot be used for distinguishing between communities but which is used to estimate the relation between diversity and environmental stress.

c Species abundance curves

Species abundance curves are obtained by plotting the number of species against the logarithm of the number of individuals as sampling units accumulate. For any one community, a curve of this sort should be a constant.

VIII ESTIMATION OF PRODUCTIVITY

A Primary or Autotrophic Productivity

1 Phytoplankton[18]

a Light and dark bottle method

Replicates of three glass stoppered bottles are filled to overflowing with a phytoplankton suspension. Two are clear; the third is coated all over with light-proof paint. The dissolved oxygen in one of the clear ones is determined. The other two are exposed to light for four hours and the dissolved oxygen in each determined. Since oxygen is a product of photosynthesis and the amount is proportional to the carbohydrate produced, the increase of dissolved oxygen in the second clear bottle corrected for the decrease in the dark bottle is a measure of photosynthesis hence productivity.

b C^{14} Method[18]

A measured amount of radioactive CO_2^{14} as bicarbonate is added to a series of replicates of bottles fitted to overflowing with a phytoplankton suspension. After a period of exposure to light, the contents are filtered through membrane filters. The radioactivity of the latter is a measure of the CO_2 taken up by the phytoplankton. The CO_2 is proportional to the carbohydrate produced by photosynthesis.

2 Higher aquatic plants

a Change in biomass[37, 38]

An increase in biomass as weight of representative samples of the higher plants over a period of time is a measure of productivity.

b Dissolved oxygen[39]

In a narrow, shallow estuary, changes in the oxygen content over a twenty-four hour period of the water flowing over a grass bed can be used as an estimate of the bed's productivity.

3 Salt marshes[40]

a Grass productivity

The productivity of the marsh grass over a period of time is best estimated on the basis of change in biomass.

b Detritus productivity

Periodic collection of detritus carried off the marsh by the falling tide may be used as a basis for estimating, by weight, the amount of detritus produced by the salt marsh.

B Consumer or Heterotrophic Productivity

Consumer, or heterotrophic productivity cannot easily be routinely estimated by laboratory procedures. We are therefore dependent on population statistics obtained by sampling programs or from the fisheries.

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This outline was prepared by Dr. Henry Kritzler, Professor of Biological Oceanography, Florida State University.

CASE PREPARATION AND COURTROOM PROCEDURE

I TYPES OF PROCEEDINGS IN WHICH WATER QUALITY EVIDENCE MAY BE USED

A Administrative Proceedings

- 1 Rule making
    - a Setting up of regulations having general application, e.g., stream classifications and implementation plan target dates
    - b Factors of safety and absolute prohibitions may be appropriate
- 2 Adjudications
    - a Determinations by agency having expertise with respect to particular discharge or discharger, e.g., approval of plans and specs and time schedule of a particular discharger

B Court Actions

- 1 Civil in behalf of state or federal government
    - a Actions to compel action or suspension of action - nuisance, health hazard, etc., --including court action following federal conference --hearing procedure
    - b Violations of Water Quality Standards
    - c Violations of Effluent Standards or discharge permits
    - d Tort or contract actions relating to design and/or operation of treatment facilities
- 2 Criminal (dependent on content of applicable statutes).
    - a Discharge of specific materials
    - b Discharges from specific industries
    - c Littering
    - d Discharges harmful to fish and/or crustaceans
    - e Discharges harmful to specific types of receiving waters
    - f Discharges of poisons

      NOTE--In some of these situations doing the act may constitute the violation; in others proof of intent or knowledge of effects may also have to be proved.
- 3 Private actions for damages or to compel action
    - a Alleged harm to plaintiff, e.g., pollution of stream killing animals

C Procedural Matters

- 1 See Attached sheet "Administrative and Court Proceedings" on Burden of proof, fact finding, and methods of presentation of evidence.

D Classes of Evidence - General Rules

- 1 Facts - direct
    - a The material was floating from the outfall.
- 2 Derived values - expert testimony - test results and/or opinion as to effects
    - a The D.O. was zero; the waterway was polluted; the plant can be built in 6 months.
- 3 Hearsay
    - a Joe told me

4 Relevancy

5 Admissibility vs. weight

  a Even if admissible, the weight to be given is up to fact finder--credibility.

E Admissibility of Results of Sampling and Testing (Numbers)

1 Sampling

  a Chain of custody

  b Tags, etc.

  c Containers

  d Place and time

  e Retention of samples (Proving that the sample represents what is at issue in the action (relevancy), that there has been no opportunity for tampering; and availability of portions for analysis by other side (non-transitory criteria)).

2 Analysis

  a Who performed (Can identity of each participant be shown?)

  b Admission through supervisor - custodian

  c Scientific acceptance of method. Is there a particular method required to be used by the agency?

  d Propriety of conduct

  e Retention of bench cards and other indicia of results. (Your attorney can make arrangements to substitute copies for originals).

3 Tests

  a Comparison with actual conditions

  b Mathematical models - how can a computer be cross-examined?

F Admissibility of Expert Opinion on Causes and Effects

1 Who has special knowledge - and of what particular areas?

2 Indicators

3 Significance of numerical determinations or observations

4 Consistency with own prior publications and testimony

5 Have underlying facts been or need to be proved--first hand information of this and/or comparable situations.

6 Use of treatises

G Conduct on the Witness Stand

1 General

  a On direct - know what counsel will ask and let him know generally what you will answer, but don't make it sound rehearsed.

  b Use layman's language to extent possible.

  c Listen to question and answer it to best of your ability.

  d Speak so that court reporter, judge, jury, and counsel can hear you.

  e Speak in language that will be understood; don't talk down.

  f Answer only what you are asked --don't volunteer; however, answer with precision.

  g There is nothing wrong with asking to have a question repeated or rephrased.

  h There is nothing wrong with saying that you consulted with your attorney before you testified, but beware of the question "Did Mr. X tell you what to say?"

i There is nothing wrong with thinking out your answer before responding.

j You are not expected to know all the answers--if you do not know, admit it.

k Don't attempt to answer questions outside your area of personal knowledge (hearsay) or beyond your expertise. (Your may be an expert on conducting laboratory tests, but not on epidimeological inferences from results).

l Don't try to answer before the judge rules on objection.

m Show that you are an impartial dispenser of information and/or opinion, not a protagonist.

n Don't be afraid to admit what may appear to be damaging.

2 If you are testifying as an expert:

a Establish qualifications -- give information relevant to your area of expertise -- educational (including this course?), work, publications, number of times you have testified previously.

b Differentiate between physical facts (measurements and observations) and opinion (derived values).

c Be prepared to discuss theory (including assumptions) instruments used, techniques(including choice of a particular technique), physical limitations and errors, interferences.

d If experiments were conducted, be able to justify both as to theory and relevancy to this litigation.

e If you're being paid to testify, admit it.

3 Scientific personnel as advisers to counsel:

a Review and refamiliarize self with materials before you discuss with your attorney.

b Be in a position to present all facts known to you simply and concisely: Who, What, When, Where, and Why, How.

c Don't overlook facts and/or test results because you don't think they're important. Let attorney decide what he needs.

d Use of standard report forms

e Ability to recommend additional witnesses with needed specialized knowledge

f Ability to aid in cross-examination of other side's experts and reconcile opinions and/or results

g Be candid - sometimes better not to start a lawsuit or accept a settlement than lose in the end.

H Non-Verbal Presentation of Evidence

1 Exhibits - including photographs

2 Summaries

3 Business and/or government records

a Prepared contemporaneously and in usual course of activities

4 Pre-prepared direct examination

a Usually limited to actions before ICC, FPC, and other federal agencies.

I Criminal Procedure

1 Privilege Against Self Incrimination (available only to persons)

a Warning and suspects

b Effect of duty to report spills

   - c Effect of duty to obtain license or permit and/or furnish operating reports
   - d Immunity from prosecution

2 Double Jeopardy

3 Unreasonable search and seizure

   - a Available to persons and corporations

4 Procedures and need for arrest and search warrants --possible cause

This outline was prepared by David I. Shedroff, Enforcement Analyst, Office of Enforcement and General Counsel, Cincinnati Field Investigations Center, 5555 Ridge Avenue, Cincinnati, OH 45268.

Descriptors: Courtroom Procedure, Law Enforcement, Legal Aspects, Sampling, Water Analysis, Water Pollution Control, Water Quality Standards

Administrative & Court Proceedings, and Excerpts from Revised Draft of Proposed Rules of Evidence for the United States Courts can be found on the following pages.

ADMINISTRATIVE & COURT PROCEEDINGS

Court or Agency	Fact Finder	Burden of Proof	Comments
State Pollution Control Agency	Agency	As per statute - usually weight of evidence.	Hearing may be conducted by hearing examiner, agency member, or full agency. Appeal may be on facts and law or law alone, depending on statute.
Rule making-adjudication			
Federal Water Pollution Control Act			
Conference	Head of agency		Reports acceptable.
Hearing	Hearing Board		Specific testimony.
Court	Judge		Uses prior material, and may take additional testimony.
Court			
Civil Case -- - for money only	Judge or jury	Weight of evidence	
- injunction			
preliminary or temporary	Judge	Must show immediate harm or danger.	Must also show likelihood of success at final hearing - bond required for non-government plaintiff.
permanent	Judge	Usually clear and convincing.	"Balance Equities"
- administrative appeal	Judge - whether "arbitrary and capricious" or substantial evidence.		Sometimes have complete new trial.
Criminal case includes penalties	Jury unless waived.	Beyond reasonable doubt.	Proof of intent may be required.

Excerpts from Revised Draft of Proposed
RULES OF EVIDENCE FOR THE UNITED STATES COURTS

GENERAL PROCEDURES

Rule 102.
PURPOSE AND CONSTRUCTION

These rules shall be construed to secure fairness in administration, elimination of unjustifiable expense and delay, and promotion of growth and development of the law of evidence to the end that the truth may be ascertained and proceedings justly determined.

Rule 101.
PRELIMINARY QUESTIONS

(a) Questions of Admissibility Generally. Preliminary questions concerning the qualification of a person to be a witness, the existence of a privilege, or the admissibility of evidence shall be determined by the judge, subject to the provisions of subdivision (b). In making his determination he is not bound by the rules of evidence except those with respect to privileges.

(b) Relevancy Conditioned on Fact. When the relevancy of evidence depends upon the fulfillment of a condition of fact, the judge shall admit it upon, or subject to, the introduction of evidence sufficient to support a finding of the fulfillment of the condition.

Rule 615.
EXCLUSION OF WITNESSES

At the request of a party the judge shall order witnesses excluded so that they cannot hear the testimony of other witnesses, and he may make the order of his own motion. This rule does not authorize exclusion of (1) a party who is a natural person, or (2) an officer or employee of a party which is not a natural person designated as its representative by its attorney, or (3) a person whose presence is shown by a party to be essential to the presentation of his cause.

Rule 611.
MODE AND ORDER OF INTERROGATION AND PRESENTATION

(a) Control by Judge. The judge may exercise reasonable control over the mode and order of interrogating witnesses and presenting evidence so as to (1) make the interrogation and presentation effective for the ascertainment of the truth, (2) avoid needless consumption of time, and (3) protect witnesses from harassment or undue embarrassment.

(b) Scope of Cross-Examination. A witness may be cross-examined on any matter relevant to any issue in the case, including credibility. In the interests of justice, the judge may limit cross-examination with respect to matters not testified to on direct examination.

Rule 613.

PRIOR STATEMENTS OF WITNESSES

(a) Examining Witness Concerning Prior Statement. In examining a witness concerning a prior statement made by him, whether written or not, the statement need not be shown or its contents disclosed to him at that time, but on request the same shall be shown or disclosed to opposing counsel.

JUDICIAL NOTICE

Rule 201.

JUDICIAL NOTICE OF ADJUDICATIVE FACTS

(b) Kinds of Facts. A judicially noticed fact must be one not subject to reasonable dispute in that it is either (1) generally known within the territorial jurisdiction of the trial court or (2) capable of accurate and ready determination by resort to sources whose accuracy cannot reasonably be questioned.

(g) Instructing Jury. The judge shall instruct the jury to accept as established any facts judicially noticed.

RELEVANCE

Rule 401.

DEFINITION OF "RELEVANT EVIDENCE"

"Relevant evidence" means evidence having any tendency to make the existence of any fact that is of consequence to the determination of the action more probable or less probable than it would be without the evidence.

Rule 402.

RELEVANT EVIDENCE GENERALLY ADMISSIBLE; IRRELEVANT EVIDENCE INADMISSIBLE

All relevant evidence is admissible, except as otherwise provided by these rules, by other rules adopted by the Supreme Court, by Act of Congress, or by the Constitution of the United States. Evidence which is not relevant is not admissible.

COMPETENCY OF WITNESSES

Rule 601.

GENERAL RULE OF COMPETENCY

Every person is competent to be a witness except as otherwise provided in these rules.

Rule 602.

LACK OF PERSONAL KNOWLEDGE

A witness may not testify to a matter unless evidence is introduced sufficient to support a finding that he has personal knowledge of the matter. Evidence to prove personal knowledge may, but need not, consist of the testimony of the witness himself. This rule is subject to the provisions of Rule 703, relating to opinion testimony by expert witnesses.

EXPERT TESTIMONY

Rule 702.

TESTIMONY BY EXPERTS

If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise.

Rule 703.

BASES OF OPINION TESTIMONY BY EXPERTS

The facts or data in the particular case upon which an expert bases an opinion or inference may be those perceived by or made known to him at or before the hearing. If of a type reasonably relied upon by experts in the particular field in forming opinions or inferences upon the subject, the facts or data need not be admissible in evidence.

Rule 705.

DISCLOSURE OF FACTS OR DATA UNDERLYING EXPERT OPINION

The expert may testify in terms of opinion or inference and give his reasons therefore without prior disclosure of the underlying facts or data, unless the judge requires otherwise. The expert may in any event be required to disclose the underlying facts or data on cross-examination.

Rule 706.

COURT APPOINTED EXPERTS

(a) Appointment. The judge may on his own motion or on the motion of any party enter an order to show cause why expert witnesses should not be appointed, and may request the parties to submit nominations. The judge may appoint any expert witnesses agreed upon by the parties, and may appoint witnesses of his own selection. An expert witness shall not be appointed by the judge unless he consents to act. A witness so appointed shall be informed of his duties by the judge in writing, a copy of which shall be filed with the clerk, or at a conference in which the parties shall have opportunity to participate. A witness so appointed shall advise the parties of his findings, if any; his deposition may be taken by any party; and he may be called to testify by the judge or any party. He shall be subject to cross-examination by each party, including a party calling him as a witness.

HEARSAY

Rule 801.

DEFINITIONS

The following definitions apply under this Article:

(a) Statement. A "statement" is (1) an oral or written assertion or (2) nonverbal conduct of a person, if it is intended by him as an assertion.

(b) Declarant. A "declarant" is a person who makes a statement.

(c) Hearsay. "Hearsay" is a statement, other than one made by the declarant while testifying at the trial or hearing, offered in evidence to prove the truth of the matter asserted.

Rule 802.

HEARSAY RULE

Hearsay is not admissible except as provided by these rules or by other rules adopted by the Supreme Court or by Act of Congress.

Rule 803.

HEARSAY EXCEPTIONS: AVAILABILITY OF DECLARANT IMMATERIAL

The following are not excluded by the hearsay rule, even though the declarant is available as a witness:

(5) Recorded Recollection. A memorandum or record concerning a matter about which a witness once had knowledge but now has insufficient recollection to enable him to testify fully and accurately, shown to have been made when the matter was fresh in his memory and to reflect that knowledge correctly. If admitted, the memorandum or record may be read into evidence but may not itself be received as an exhibit unless offered by an adverse party.

(6) Records of Regularly Conducted Activity. A memorandum, report, record, or data compilation, in any form, of acts, events, conditions, opinions, or diagnoses, made at or near the time by, or from information transmitted by, a person with knowledge, all in the course of a regularly conducted activity, as shown by the testimony of the custodian or other qualified witness, unless the sources of information or other circumstances indicate lack of trustworthiness.

(18) Learned Treatises. To the extent called to the attention of an expert witness upon cross-examination or relied upon by him in direct examination, statements contained in published treatises, periodicals, or pamphlets on a subject of history, medicine, or other science or art, established as a reliable authority by the testimony or admission of the witness or by other expert testimony or by judicial notice. If admitted, the statements may be read into evidence but may not be received as exhibits.

IDENTIFICATION OF PERSONS AND SAMPLES

Rule 901.

REQUIREMENT OF AUTHENTICATION OR IDENTIFICATION

(a) General Provision. The requirement of authentication or identification as a condition precedent to admissibility is satisfied by evidence sufficient to support a finding that the matter in question is what its proponent claims.

(b) Illustrations. By way of illustration only, and not by way of limitation, the following are examples of authentication or identification conforming with the requirements of this rule:

(1) Testimony of Witness with Knowledge. Testimony that a matter is what it is claimed to be.

(3) Comparison by Trier or Expert Witness. Comparison by the trier of fact or by expert witnesses with specimens which have been authenticated.

(9) Process or System. Evidence describing a process or system used to produce a result and showing that the process or system produces accurate result.

ADMISSIBILITY AND PROOF OF SPECIAL MATTERS

Rule 406.

HABIT; ROUTINE PRACTICE

(a) Admissibility. Evidence of the habit of a person or of the routine practice of an organization, whether corroborated or not and regardless of the presence of eyewitnesses, is relevant to prove that the conduct of the person or organization on a particular occasion was in conformity with the habit or routine practice.

(b) Method of Proof. Habit or routine practice may be proved by testimony in the form of an opinion or by specific instances of conduct sufficient in number to warrant a finding that the habit existed or that the practice was routine.

Rule 612

WRITING USED TO REFRESH MEMORY

If a witness uses a writing to refresh his memory, either before or while testifying, an adverse party is entitled to have it produced at the hearing, to inspect it, to cross-examine the witness thereon, and to introduce in evidence those portions which relate to the testimony of the witness.

Rule 1006.

SUMMARIES

The contents of voluminous writings, recordings, or photographs which cannot conveniently be examined in court may be presented in the form of a chart, summary, or calculation. The originals, or duplicates, shall be made available for examination or copying, or both, by other parties at a reasonable time and place. The judge may order that they be produced in court.